Crop Fertilization Based on North Carolina Soil Tests

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Foreword

The Agronomic Division of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) works to increase crop productivity, promote responsible land management and protect the environment. To achieve those ends, the Division provides diagnostic and advisory services for all North Carolina residents. It also works closely with educational institutions and agribusinesses.

The Soil Testing section analyzes soil samples to calculate fertilizer and lime requirements for crops grown throughout the state. By clarifying a soil's relative nutrient-supplying capability, soil tests help maximize amendment efficiency. Growers can then avoid nutrient deficiencies without applying economically wasteful and environmentally unsound excesses.

This laboratory provides *predictive* soil tests for all state residents. These tests clarify fertility status with regard to pH, acidity and nutrient levels. Site-specific recommendations are then based on crop requirements, soil type, and current pH and fertility levels.

It also provides a *diagnostic* service for solving problems during the growing season, thus allowing users to adjust amendments to site- and season-specific demands.

In response to public concern about the environment, soil tests now analyze for heavy metals in soil samples from sites where municipal, animal or industrial wastes have been applied. This monitoring can prevent the indiscriminate use of such wastes and thus protect land productivity, surface-water and groundwater quality, food safety and human health.

This document outlines

- the philosophical framework employed by the Agronomic Division's Soil Testing section,
- the methodologies and equations it uses to calculate fertilizer and lime recommendations,
- the crop-specific details growers must consider when applying these recommendations,
- conversion factors and equivalencies useful in calculating fertilizer requirements, and
- specifics on fertilizer properties, sources and application.

Parts I and II answer the *what*, *why* and *how* questions concerning our soil testing service. Intended for readers interested in the scientific foundations of our work, the text describes *what* testing procedures we employ, *why* we employ them, and *how* we move from soil test data to site- and crop-specific fertilizer and lime recommendations. Detailed equations and tables enable readers to recalculate recommendations should they wish to grow a crop other than the one listed on the soil sample report.

Part III contains a series of notes that address the fertilization requirements of specific crops or groups of crops grown in North Carolina. Relevant notes are typically appended as a supplement to the soil test report. Readers who are not interested in the technical procedures used to derive recommendations may prefer to turn directly to Part III.

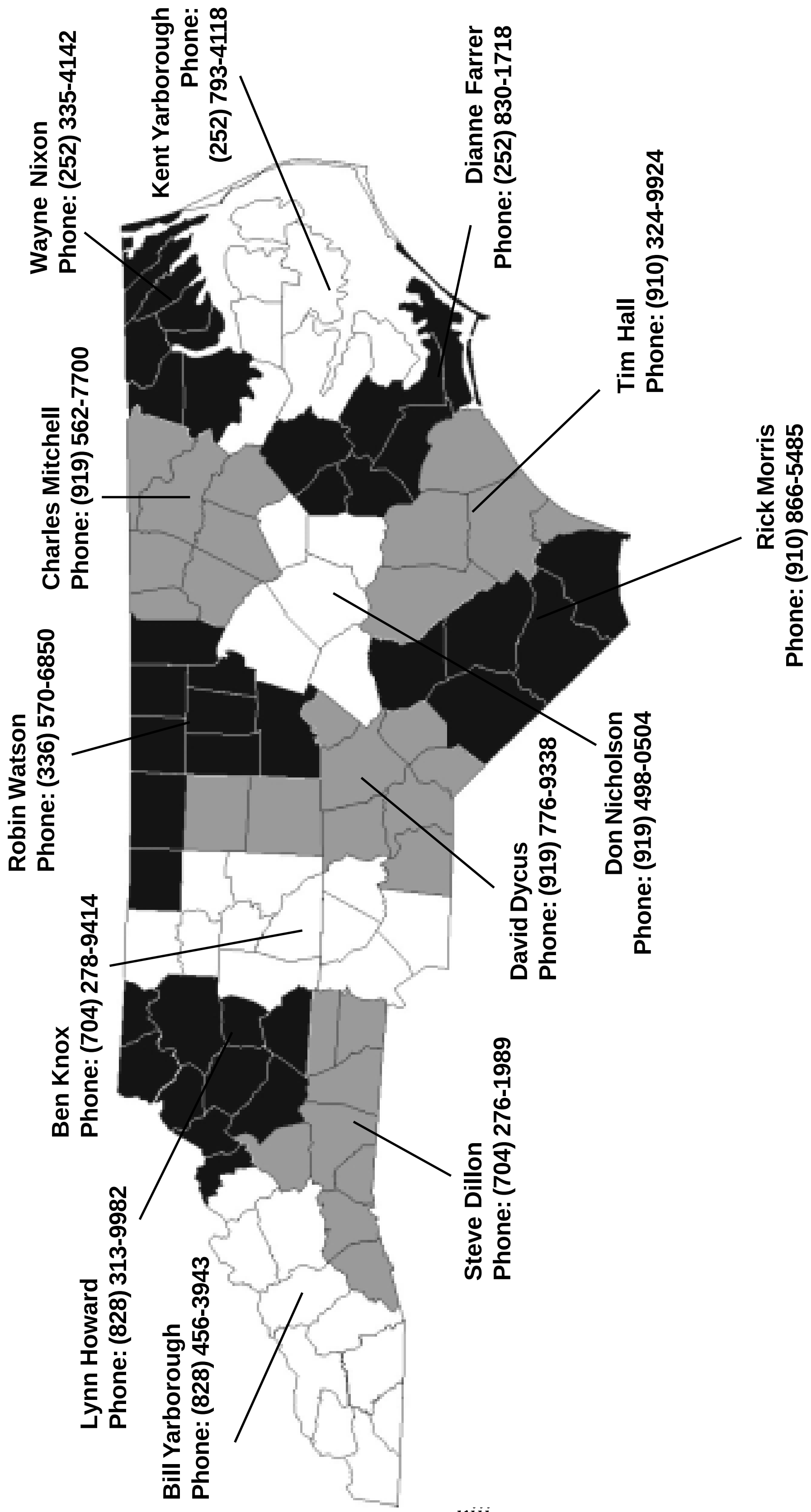

Figure F.1 Jurisdictions of NCDA&CS regional agronomists.

Part IV provides tables of information that may be useful when calculating fertilizer requirements or when deciding which fertilizer to apply. Conversion factors, equivalencies, properties, sources and application methods are addressed.

In addition to the soil testing services discussed in this document, the Agronomic Division also provides nematode assay, plant tissue analysis, waste analysis, solution analysis, and field advisory services.

Contact Information

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David H. Hardy, Ph.D.
Soil Testing Section Chief

Regional Agronomists (see Figure F.1) also provide assistance statewide. They can make on-site farm visits to address a wide range of nutrient-related crop concerns.

Acknowledgments

Dr. Adolf Mehlich (1902–1983)

Dr. Adolf Mehlich served the North Carolina Department of Agriculture as a consultant in soil test methodology in 1953 and again from 1970 until his death in 1983. His life was dedicated to understanding the chemical, mineralogical, physical and microbiological characteristics of soils.

Dr. Mehlich's insight into the interaction of soil characteristics and plant nutrition was keen. He developed a volumetric method for testing, calculating and expressing soil test results on a field basis. He authored or co-authored over 70 journal articles and six chapters in books. He advised many students and was an active consultant to his peers. Dr. Mehlich received the award of "Fellow" from the American Society of Agronomy and the Soil Science Society of America in 1982. His contributions to soil science and their influence on plant nutrition have gained international renown.

The Mehlich-1 extractant is used by laboratories across the southeastern United States and in several Latin American countries. The Mehlich-3, introduced in 1984, extracts major nutrients, as well as micronutrients, from soils with a wide range of chemical and physical properties. This extractant has been used by many state and private laboratories worldwide, including the NCDA&CS Agronomic Division laboratory.

Several solutions used by soil test laboratories to extract nutrients bear Dr. Mehlich's name:

Mehlich-1
composition: 0.05N HCl + 0.025N H_2SO_4
usage: 25 cm^3 extractant per 5 cm^3 soil
reference: (Mehlich 1953)

Mehlich-2
composition: 0.2N CH_3COOH + 0.015N NH_4F + 0.2N NH_4Cl + 0.012N HCl
usage: 25 cm^3 extractant per 2.5 cm^3 soil
reference: (Mehlich 1978)

Mehlich-3
composition: 0.2N CH_3COOH + 0.25N NH_4NO_3 + 0.013N HNO_3 + 0.015N NH_4F + 0.001M EDTA
usage: 25 cm^3 extractant per 2.5 cm^3 soil
reference: (Mehlich 1984)

Dr. Mehlich also developed methods for measuring soil acidity and humic matter (Mehlich 1976, 1984). These methods are still being used by the NCDA&CS Agronomic Division laboratory. Dr. Mehlich's efforts have enhanced our capability to measure the nutrient content of soils as well as the availability of nutrients to crops under diverse soil conditions. These contributions enable soil testing laboratories to make more precise lime and fertilizer recommendations. As a result, they foster economic yields.

References

Mehlich A. 1953. Determination of P, Ca, Mg, K, Na, NH_4. Raleigh (NC): North Carolina Department of Agriculture, Agronomic Division. Soil Testing Division Publication No. 1-53.

Mehlich A. 1976. New buffer pH method for rapid estimation of exchangeable acidity and lime requirement of soils. Commun Soil Sci Plant Anal 7(7): 636–52.

Mehlich A. 1978. New extractant for soil test evaluation of phosphorus, potassium, magnesium, calcium, sodium, manganese and zinc. Commun Soil Sci Plant Anal 9(6): 477–92.

Mehlich A. 1984. Mehlich-3 soil test extractant: a modification of Mehlich-2 extractant. Commun Soil Sci Plant Anal 15(12): 1409–16.

Mehlich A. 1984. Photometric determination of humic matter in soils. A proposed method. Commun Soil Sci Plant Anal 15(12): 1417–22.

Part I. NCDA&CS's Approach to Soil Testing

Fertility is not the only factor that limits yield. Soil pH, soil moisture, planting dates, crop varieties, weeds, insects, diseases, nematodes, soil physical conditions and other variables also limit production. Therefore, the goal of Agronomic Division soil test recommendations is not to achieve a specific yield but to prevent fertility from being a yield-limiting factor. Additionally, soil test recommendations help curb excessive nutrient application, which is both economically and environmentally unsound.

Lime and fertilizer recommendations from the Agronomic Division are based on analysis of the soil, the cropping history provided by the grower, field studies and typical climatic conditions. The information sheet that a grower submits with soil samples appears in Figure 1.1. The soil test report generated from those samples appears in Figure 1.2.

Volumetric Soil Testing

The Agronomic Division analyzes soil samples by volume, not by weight. Why? The answer is because plant roots obtain nutrients from a volume of soil regardless of the soil's weight per unit volume. Volume-based analyses are thus the most accurate means of assessing nutrient status in the field plow zone.

Volumetric testing maintains a constant ratio between soil volume and extracting solution, regardless of the soil's weight/volume ratio. This ratio can vary widely, as in sandy versus clay soils. Procedures based on soil weight use the same amount of extractant regardless of soil volume. Results based on such a process can produce a misleading picture of nutrient availability in the root zone. Having determined that volume is a more useful indicator than weight for determining fertilizer recommendations, the Agronomic Division maintains a fixed soil-volume/extractant ratio and allows the soil-weight/extractant ratio to fluctuate.

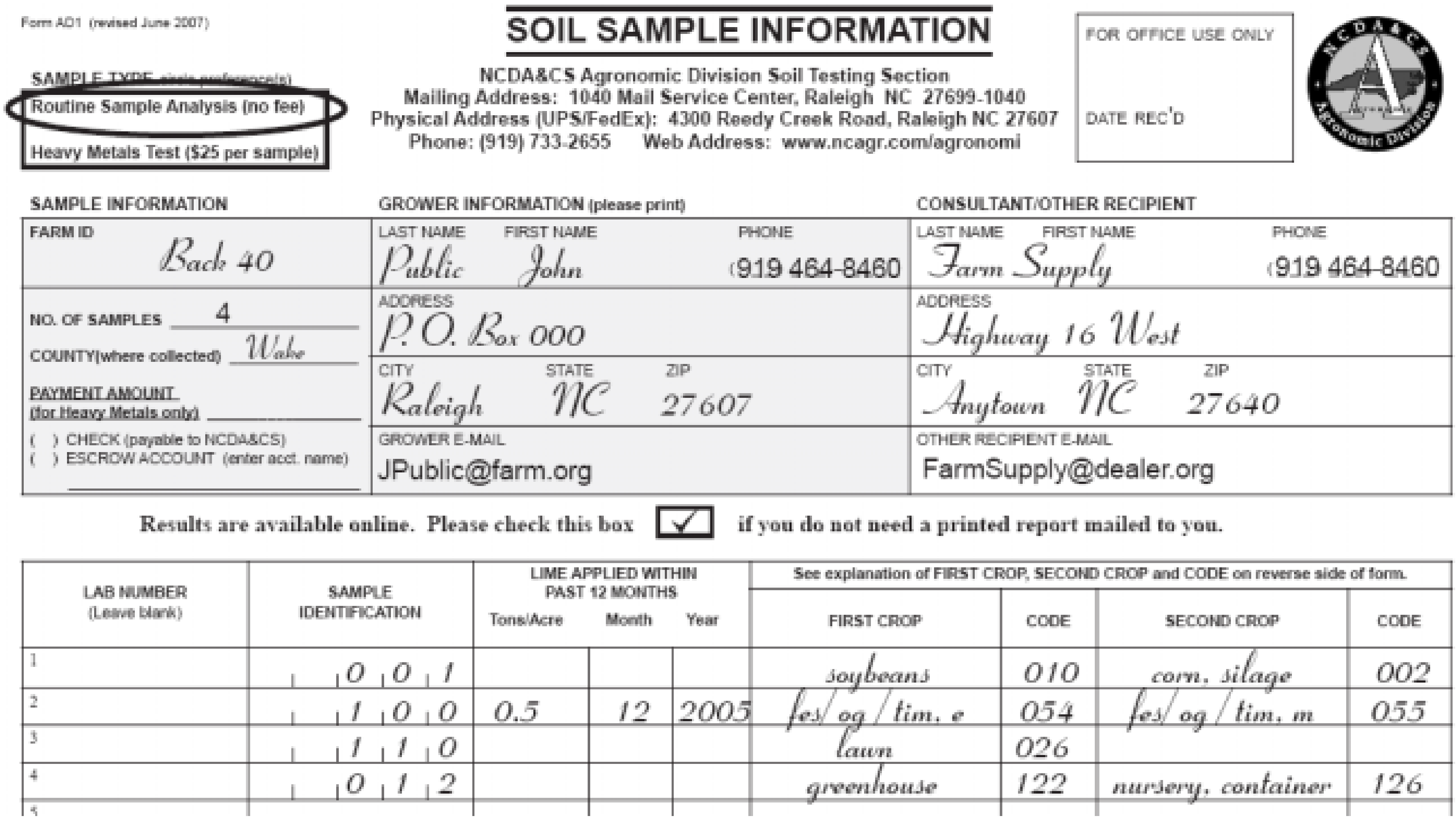
The Soil Analysis

NCDA&CS soil tests evaluate 22 factors. The first seven [soil class, HM%, W/V, CEC, BS%, Ac and pH] describe the soil and its degree of acidity. The other 15 [P-I, K-I, Ca%, Mg%, Mn-I, Mn-AI (1), Mn-AI (2), Zn-I, Zn-AI, Cu-I, S-I, SS-I, NO_3-N, NH_4-N and Na] indicate levels of plant nutrients or other fertility measurements. The nutrients are reported in one of two ways:

- as a standardized index [for phosphorus, potassium, manganese, zinc, copper and sulfur] or
- as a percentage of the cation exchange capacity [for calcium and magnesium].

These methods are explained in the next sections.

In most cases, nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), boron (B) and soluble salt (SS) contents of the soil are not measured. The circumstances that might justify testing for these factors vary and are covered later in the section **SPECIAL CASES.**



Form AD1 (revised June 2007)

SOIL SAMPLE INFORMATION

NCDA&CS Agronomic Division Soil Testing Section
Mailing Address: 1040 Mail Service Center, Raleigh NC 27699-1040
Physical Address (UPS/FedEx): 4300 Reedy Creek Road, Raleigh NC 27607
Phone: (919) 733-2655 Web Address: www.ncagr.com/agronomi

FOR OFFICE USE ONLY

DATE REC'D

SAMPLE TYPE circle preference(s)

Routine Sample Analysis (no fee)

Heavy Metals Test ($25 per sample)

SAMPLE INFORMATION

FARM ID: Back 40

NO. OF SAMPLES: 4

COUNTY(where collected): Wake

PAYMENT AMOUNT (for Heavy Metals only): ______

( ) CHECK (payable to NCDA&CS)
( ) ESCROW ACCOUNT (enter acct. name) ______

GROWER INFORMATION (please print)

LAST NAME: Public FIRST NAME: John PHONE: (919 464-8460

ADDRESS: P.O. Box 000

CITY: Raleigh STATE: NC ZIP: 27607

GROWER E-MAIL: JPublic@farm.org

CONSULTANT/OTHER RECIPIENT

LAST NAME: Farm FIRST NAME: Supply PHONE: (919 464-8460

ADDRESS: Highway 16 West

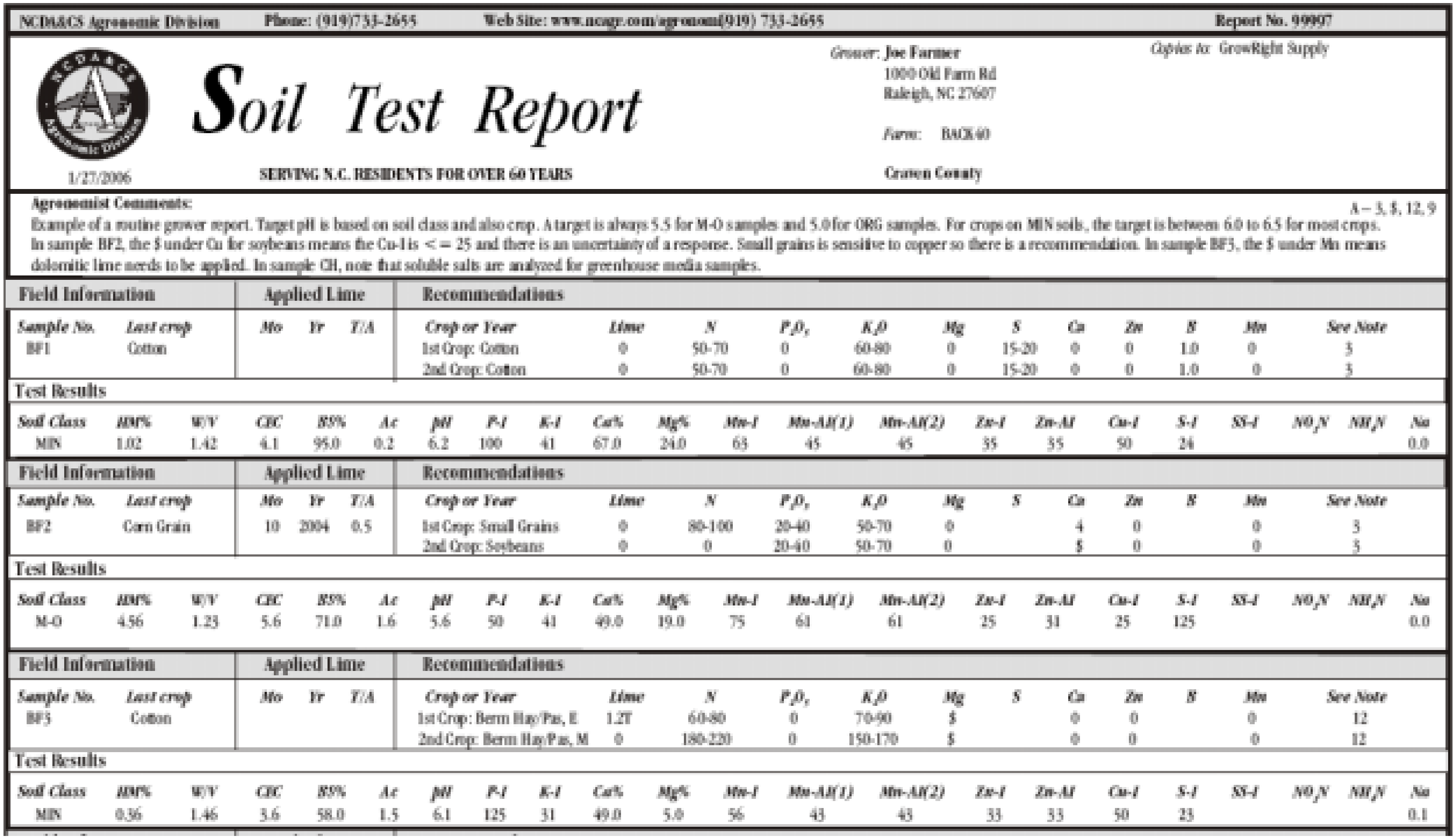
CITY: Anytown STATE: NC ZIP: 27640

OTHER RECIPIENT E-MAIL: FarmSupply@dealer.org

Results are available online. Please check this box ☑ if you do not need a printed report mailed to you.

LAB NUMBER (Leave blank)	SAMPLE IDENTIFICATION	LIME APPLIED WITHIN PAST 12 MONTHS			See explanation of FIRST CROP, SECOND CROP and CODE on reverse side of form.			
		Tons/Acre	Month	Year	FIRST CROP	CODE	SECOND CROP	CODE
1	001				soybeans	010	corn, silage	002
2	100	0.5	12	2005	fes/og/tim, e	054	fes/og/tim, m	055
3	110				lawn	026		
4	012				greenhouse	122	nursery, container	126
5								

Figure 1.1 Soil sample information sheet



NCDA&CS Agronomic Division | Phone: (919)733-2655 | Web Site: www.ncagr.com/agronomi(919) 733-2655 | Report No. 99997

Soil Test Report

SERVING N.C. RESIDENTS FOR OVER 60 YEARS

1/27/2006

Grower: Joe Farmer
1000 Old Farm Rd
Raleigh, NC 27607

Farm: BACK40

Craven County

Copies to: GrowRight Supply

Agronomist Comments: A – 3, $, 12, 9

Example of a routine grower report. Target pH is based on soil class and also crop. A target is always 5.5 for M-O samples and 5.0 for ORG samples. For crops on MIN soils, the target is between 6.0 to 6.5 for most crops. In sample BF2, the $ under Cu for soybeans means the Cu-I is < = 25 and there is an uncertainty of a response. Small grains is sensitive to copper so there is a recommendation. In sample BF3, the $ under Mn means dolomitic lime needs to be applied. In sample CH, note that soluble salts are analyzed for greenhouse media samples.

Field Information / Applied Lime / Recommendations

Sample No.	Last crop	Mo	Yr	T/A	Crop or Year	Lime	N	P_2O_5	K_2O	Mg	S	Cu	Zn	B	Mn	See Note
BF1	Cotton				1st Crop: Cotton	0	50-70	0	60-80	0	15-20	0	0	1.0	0	3
					2nd Crop: Cotton	0	50-70	0	60-80	0	15-20	0	0	1.0	0	3
BF2	Corn Grain	10	2004	0.5	1st Crop: Small Grains	0	80-100	20-40	50-70	0		4	0		0	3
					2nd Crop: Soybeans	0	0	20-40	50-70	0		$	0		0	3
BF3	Cotton				1st Crop: Berm Hay/Pas, E	1.2T	60-80	0	70-90	$		0	0		0	12
					2nd Crop: Berm Hay/Pas, M	0	180-220	0	150-170	$		0	0		0	12

Test Results

Sample	Soil Class	HM%	W/V	CEC	BS%	Ac	pH	P-I	K-I	Ca%	Mg%	Mn-I	Mn-AI(1)	Mn-AI(2)	Zn-I	Zn-AI	Cu-I	S-I	SS-I	NO_3-N	NH_4-N	Na
BF1	MIN	1.02	1.42	4.1	95.0	0.2	6.2	100	41	67.0	24.0	63	45	45	35	35	50	24				0.0
BF2	M-O	4.56	1.23	5.6	71.0	1.6	5.6	50	41	49.0	19.0	75	61	61	25	31	25	125				0.0
BF3	MIN	0.36	1.46	3.6	58.0	1.5	6.1	125	31	49.0	5.0	56	43	43	33	33	50	23				0.1

Figure 1.2 NCDA&CS soil test report.

—Soil classification and acidity

The first seven factors evaluated on the soil test report describe the soil and indicate the degree of acidity. These factors are soil class, percent humic matter (HM%), weight per volume (W/V), cation exchange capacity (CEC), base saturation as a percent of CEC (BS%), acidity (Ac) and pH. These data have a bearing on the amount of lime a crop needs.

Soils belong to one of three classes based on HM% and W/V: mineral (MIN), mineral organic (M-O) or organic (ORG). Plants can tolerate more acidity in organic soils than in mineral soils because organic soils contain less aluminum. Therefore, soil class exerts considerable influence on lime recommendations.

Percent humic matter (HM%) is a measure of the portion of organic matter that has decomposed to form humic and fulvic acids. HM% represents the portion of organic matter that is chemically reactive. This value affects determinations of lime and herbicide rates.

The weight-per-volume ratio (W/V) is a good indicator of soil texture. Very sandy soils often weigh more than 1.5 g/cm^3, silt and clay loams near 1.0 g/cm^3, organics as little as 0.4 g/cm^3, and greenhouse media often even less.

Cation exchange capacity (CEC) indicates the extent to which a soil can hold and exchange basic cations such as calcium, magnesium and potassium as well as hydrogen, aluminium, iron and manganese. The CEC of North Carolina soils ranges from 40 or more meq/100 cm^3 in clay and organic soils to 2 or less in some sandy soils. A high CEC is desirable because it makes leaching of fertilizer nutrients less likely and the maintenance of high reserve quantities more likely. The CEC will vary as pH changes and as organic matter fluctuates through addition or decomposition.

Percent base saturation (BS%) is the portion of the CEC that is occupied primarily by the nutrient cations calcium, magnesium and potassium. A high base saturation reduces soil acidity levels and increases the supply of other plant nutrients. Therefore, high BS% values are favorable for plant growth.

Exchangeable acidity (Ac) is a quantitative measurement of the portion of the CEC occupied by acidity factors, such as hydrogen and aluminum. The acidity in organic soils ranges from 4 to 8 meq whereas in mineral soils, it ranges from about 0.5 to 2.5 meq/100 cm^3. The amount of acidity increases in both soils as pH decreases.

Hydrogen ion concentration (pH) is an index of the active acidity in a soil at an instant in time. Soil pH values range from 3 to 8 on a scale of 1 to 14. Weather, cultural practices and additions of lime and fertilizer cause pH to fluctuate. An extremely low pH interferes with plant nutrient uptake and can even cause root damage.

—The index rating system: P, K, Mn, S, Zn & Cu

As explained on the soil test report, the Agronomic Division reports phosphorus (P), potassium (K), manganese (Mn), sulfur (S), zinc (Zn) and copper (Cu) levels as indices. The index scale used for fertilizer recommendation ranges from 0 to 100. The relationship between soil test index and fertilizer requirement is shown in Figure 1.3.

The critical quantitative value for each nutrient is assigned an index of 25. Values of 25 or below indicate low soil fertility, a high fertilizer requirement and potentially dramatic yield increases in response to fertilization. Values from 26 to 50 indicate medium fertility; those above 50, high fertility. Values above 100 are considered excessive, and crops grown on such soils show no response to fertilizer application. Certain

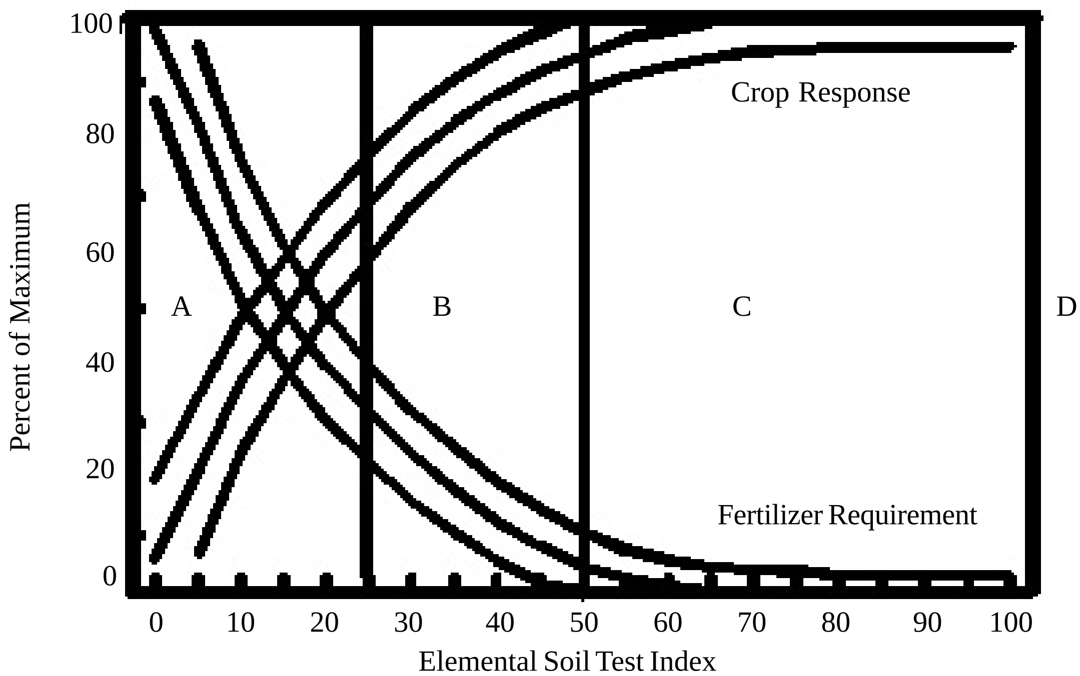


Figure 1.3 Idealized relationship between soil test index, crop response and the amount of fertilizer (P_2O_5 and K_2O) required: A — expected response very high; B — response low to medium; C — little or no response expected; and D — test levels far in excess of plant requirements, no response. [*Modified from* Hatfield AL. 1972. Soil test reporting: a nutrient index system. Commun Soil Sci Plant Anal 3(5): 425–36.]

Table 1.1 Relationship between soil test index and yield

		Crop Yield in Response to Nutrient Application				
Index Range	**Nutrient Status**	**P***	**K***	**Mn**	**Zn**	**Cu**
0–10	Very Low	high	high	high	high	high
11–25	Low	high	high	high	high	high
26–50	Medium	med/low	med/low	none	none	none
51–100	High	none	low/none	none	none	none
100+	Very High	none	none	none	none	none

*Crop response to phosphate (P_2O_5) and potash (K_2O) decreases as the soil test index approaches 50.

micronutrient levels above a 250 index can be detrimental to crops.

The quantity of each nutrient required by different crops may vary greatly. The index, however, provides a common scale for judging nutrient supply and balance in the soil. The relationship between soil test index and fertilizer response is outlined in Table 1.1.

The phosphorus index (P-I) reflects the level of phosphorus found in the soil. Values less than 100 are of concern in predicting the need for phosphate fertilizer. The amount of phosphate recommended depends on soil test level and crop requirement. Actual P-I values are shown on the soil test report.

The potassium index (K-I) reflects the level of potassium found in the soil. Values greater than 100 are of little concern with regard to fertilizer recommendations. However, the total amount of potassium present has a bearing on CEC and BS% values.

Multiple manganese values appear on soil test reports (Figure 1.2). The first value is the actual manganese index (Mn-I). Two manganese availability indices follow it: Mn-AI (1) applies to the first crop to be grown and Mn-AI (2) applies to the second crop. The Mn-AI is a function of Mn-I and pH based on crop sensitivity to manganese. Tables 1.2 and 1.3 show grids of Mn-AI values and the formulas used for calculation.

The sulfur index (S-I) that appears on the soil test report may not accurately predict the amount of sulfur available to plants on sandy coastal plain soils. Sulfur leaches from sandy topsoils and accumulates in the subsoil. Hence, subsoil samples provide a more reliable assessment of plant-available sulfur. Prediction of plant-available sulfur is more reliable for clay soils than for sandy soils because they are less subject to leaching. Piedmont and mountain soils generally contain adequate sulfur for optimum yields. Plant tissue analysis in combination with soil testing provides the best means for determining when sulfur is deficient.

Two zinc values appear in the *Test Results* section on most soil test reports. The first is the zinc index (Zn-I); the second is an availability index (Zn-AI) based on soil class. The Zn-AI equals the Zn-I for mineral soils, is 1.25 times greater for mineral-organic soils and is 1.66 times greater for organic soils. The Zn-AI is not relevant for samples from homeowners and does not appear on those soil test reports.

The copper index (Cu-I) gauges sufficiency or toxicity of this element. Only one value appears. See *Part II* for information on how to interpret Cu-I.

Factors to convert any of these nutrient indices to more recognizable quantitative equivalents are listed in Table 1.4. Notice that some of these equivalents are weights per volume and other are weights per area. NCDA&CS soil tests are conducted on a volume of soil. Conversion to a specific unit per area is based on a depth of 20 cm (7.9 inches). See the footnote to Table 1.4 for further explanation of the volumetric rationale.

—Nutrient percentage ratings: Ca & Mg

Levels of calcium (Ca) and magnesium (Mg) are expressed as percentages of the CEC, not as an index. The Ca determination is made to establish the CEC as well as the relationship between Ca and other cations. Since it is a component of lime, Ca is usually present in the soil in large quantities. The amounts of Ca and K, as well as the acid fraction of the CEC, have

Table 1.2 Manganese availability indices (Mn-AI) for manganese-sensitive crops *

Soil	Manganese Index from Soil Test Report									
pH	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
5.4	22	**25**	28	31	34	37	40	43	46	49
5.5	21	24	27	30	33	36	39	42	45	48
5.6	19	22	**25**	28	31	34	37	40	43	46
5.7	18	21	24	27	30	33	36	39	42	45
5.8	16	19	22	**25**	28	31	34	37	40	43
5.9	15	18	21	24	27	30	33	36	39	42
6.0	13	16	19	22	**25**	28	31	34	37	40
6.1	12	15	18	21	24	27	30	33	36	39
6.2	10	13	16	19	22	**25**	28	31	34	37
6.3	8	11	14	17	20	23	26	29	32	35
6.4	7	10	13	16	19	22	**25**	28	31	34
6.5	5	8	11	14	17	20	23	26	29	32
6.6	4	7	10	13	16	19	22	**25**	28	31
6.7	2	5	8	11	14	17	20	23	26	29
6.8	1	4	7	10	13	16	18	22	**25**	28
6.9	0.68	2	5	8	11	14	17	20	23	26
7.0	-	0 .8	4	7	10	13	16	19	22	**25**

* Mn-AI is calculated based on equation A [101.2 + (0.6 × Mn-I) – (15.2 × pH)] and rounded to the nearest whole number.

The critical Mn-AI = 25. Manganese-sensitive crops include cotton, peanuts, small grains, soybeans, tobacco, melons, cucurbits, beans, onions, peas, peppers, radishes, rutabagas, strawberries, tomatoes, turnips and watermelons.

Table 1.3 Manganese availability indices (Mn-AI) for crops less sensitive to manganese *

Soil pH	Manganese Index from Soil Test Report									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
5.4	29	32	35	38	41	44	47	50	53	56
5.5	28	31	34	37	40	43	46	49	52	55
5.6	26	29	32	35	38	41	44	47	50	53
5.7	**25**	28	31	34	37	40	42	45	48	52
5.8	23	26	29	32	35	38	41	44	47	50
5.9	22	**25**	28	31	34	37	40	43	46	49
6.0	20	23	26	29	32	35	38	41	44	47
6.1	19	22	**25**	28	31	34	37	40	43	46
6.2	17	20	23	26	29	32	35	38	41	44
6.3	15	18	21	**24**	27	30	33	36	39	42
6.4	14	17	20	23	26	29	32	35	38	41
6.5	12	15	18	21	**24**	27	30	33	36	39
6.6	11	14	17	20	23	26	29	32	35	38
6.7	9	12	15	18	21	**24**	27	30	33	36
6.8	8	11	14	17	20	23	26	29	32	35
6.9	6	9	12	15	18	21	**24**	27	30	33
7.0	5	8	11	14	17	20	23	26	29	32

* Mn-AI is calculated based on equation B [108.2 + (0.6 × Mn-I) – (15.2 × pH)] and rounded to the nearest whole number.

The critical Mn-AI = 25. Crops less sensitive to manganese include asparagus, beets, blueberries, Christmas treees, corn, forage grasses and legumes, pearl millet, milo, okra, irish potatoes, raspberry, rhubarb, rice, sorghum, sunflower, sweetpotatoes, and commercial nursery and flower crops.

a bearing on the need for applying magnesium to the soil. Guidelines for evaluating magnesium are given in *Part II. Lime and Fertilizer Requirements*.

—Special cases: N, B & soluble salts

Predictive soil tests generally do not measure levels of nitrogen (N), boron (B) or soluble salts (SS) in a sample. However, recommendations for nitrogen and boron fertilization appear on the soil test report. These recommendations are based on specific crop requirements under known soil and climatic conditions.

Tests for nitrogen in soil samples from field crops are not routinely conducted because they have limited predictive value. Nitrogen often leaches out of the root zone before the crop is planted. Therefore, there is little point in measuring it.

Nitrate nitrogen (NO_3-N) is evaluated routinely for greenhouse or nursery soils. Ammonium nitrogen (NH_4-N) is measured under unique

Table 1.4 Multiplication factors for converting soil test index values to a quantitative equivalent *

Nutrient	mg/dm^3	kg/ha	lb/acre	meq/100 cm^3	meq/dm^3
P-I	1.2	2.40	2.138	–	–
K-I	1.955	3.91	3.484	0.005	0.05
Ca%×CEC	200.0	400.0	356.40	1.0	10.0
Mg%×CEC	121.6	243.2	216.69	1.0	10.0
Na	230.0	460.0	409.86	1.0	10.0
Mn-I	0.16	0.32	0.285	–	–
Zn-I	0.04	0.08	0.071	–	–
Cu-I	0.02	0.04	0.036	–	–
S-I	0.48	0.96	0.857	–	–

* Soil tests in North Carolina are made on a volume of soil. Conversion to an area equivalent is based on a depth of 20 cm (7.9 inches). To convert phosphorus and potassium from the elemental forms to lb/acre, use these multipliers: 2.29 × P gives lb of P_2O_5 per acre; and 1.2 × K gives lb of K_2O per acre.

The Volume Rationale: The area of a hectare (ha) is 10,000 m^2 or 1000,000 dm^2. The volume per hectare to a depth of 20 cm or 2 dm equals 2,000,000 dm^3. The following conversion factors apply: mg/dm^3 = parts per million (ppm); mg/dm^3 × 2 = kg/ha; kg/ha × 0.893 = lb/acre; or mg/dm^3 × 1.78 = lb/acre. Refer to Part IV of this manual for other conversion factors.

diagnostic situations. Test results for both types of nitrogen are expressed in mg/dm^3 (ppm).

In the case of boron (B), no reliable soil test has been developed. Plant tissue analysis is the best method to confirm a boron deficiency. Plant analysis also provides a means to gauge the supply of boron in the soil.

Soluble salts (SS-I) are measured in greenhouse and diagnostic samples. The results are expressed in units of mhos$\times 10^{-5}$. To convert this value to conductivity measured in deciSiemens per meter (dS/m), divide by 100. Guidelines for interpreting and managing soluble salts are shown in the crop management notes that accompany the soil test report (refer to explanatory tables in *Note 9. Soil Analysis of Substrates for Greenhouse Crops*).

—Sodium levels

Sodium (Na) is analyzed on all samples and is reported in meq/100 cm^3. Sodium levels above 15 percent of the CEC can be detrimental to crop production. Such levels usually occur from salt water intrusion or application of waste products high in sodium.

Part II. Lime and Fertilizer Requirements

The amount of lime and fertilizer needed for optimum crop growth depends on the specific crop requirement, soil type and current fertility status of the soil. A soil test determines aspects of fertility such as pH, acidity and nutrient levels. This information is prerequisite to calculation of lime and fertilizer requirements.

Lime

Lime recommendations are a function of soil class, target pH, current pH, level of acidity (Ac) and residual credit (RC):

- *tons lime/acre* = *Ac* × [(*target pH* – *current pH*) ÷ (6.6 – *current pH*)] – *RC*
- *tons lime/acre* × 46 = *lb/1000 ft*^{2}

The precalculated factors listed in Table 2.1 make this determination easier. The table provides values for the factor in brackets above, based on current and target pH values.

To calculate the lime recommendation, you need the following information about the variables. Target pH is different for each soil class (Table 2.2 and Figure 2.1). Current soil pH and Ac values appear on the soil test report. RC is any amount of lime recently applied, reduced by a certain percentage for each month that has elapsed since application: 8 percent for mineral (MIN) soils and 16 percent for mineral-organic (M-O) and organic (ORG) soils. The RC decreases faster for M-O and ORG soils because lime reacts rapidly to the higher levels of acidity in these soils.

Lime recommendations are in units of tenths of a ton per acre. When calculations are less than 0.3 ton/acre, the soil test report indicates that no lime is needed. However, the current soil pH may still be slightly lower than the target pH. In this case, application of a standard rate of 0.3 ton/acre or 15 lb/1000 ft^2 is appropriate.

A special situation occurs when the second crop listed on a soil sample information sheet requires more lime than the first crop. In this case, the higher lime rate appears as the recommendation for the first crop. No lime recommendation appears for the second crop.

Two types of limestone are available for agricultural purposes: calcitic and dolomitic. Calcitic limestone contains calcium carbonate ($CaCO_3$) but no magnesium (Mg). Dolomitic limestone is a mixture of calcium and magnesium carbonates [$CaMg(CO_3)_2$] and contains at least 120 lb Mg per ton. On soils where Mg is difficult to maintain, application of dolomitic lime solves two problems in one treatment.

Nitrogen (N)

Although the soil test report does not generally indicate soil nitrogen levels, it does provide recommendations for nitrogen fertilization (Table 2.3), depending on the crop. Years of field research and observations have led to these recommendations. The crop notes (see Part III) suggest ways to vary these rates. Plant tissue analysis during the vegetative growth stage is a good indicator of nitrogen sufficiency.

Table 2.1 Factors for calculating lime rates *

Current Soil pH	Target pH 6.5	6.2	6.0	5.7	5.5	5.0
3.2	0.971	0.882	0.824	0.735	0.676	0.529
3.3	0.970	0.879	0.818	0.727	0.667	0.515
3.4	0.969	0.875	0.813	0.719	0.656	0.500
3.5	0.968	0.871	0.806	0.710	0.645	0.484
3.6	0.967	0.867	0.800	0.700	0.633	0.467
3.7	0.966	0.862	0.793	0.690	0.621	0.448
3.8	0.964	0.857	0.786	0.679	0.607	0.429
3.9	0.963	0.852	0.778	0.667	0.593	0.401
4.0	0.962	0.846	0.769	0.654	0.577	0.385
4.1	0.960	0.840	0.760	0.640	0.560	0.360
4.2	0.958	0.833	0.750	0.625	0.542	0.333
4.3	0.957	0.826	0.739	0.609	0.522	0.304
4.4	0.955	0.818	0.727	0.591	0.500	0.273
4.5	0.952	0.810	0.714	0.571	0.476	0.238
4.6	0.950	0.800	0.700	0.550	0.450	0.200
4.7	0.947	0.789	0.684	0.526	0.421	0.158
4.8	0.944	0.778	0.667	0.500	0.389	0.111
4.9	0.941	0.765	0.647	0.471	0.353	0.059
5.0	0.936	0.750	0.625	0.438	0.313	0
5.1	0.933	0.733	0.600	0.400	0.267	
5.2	0.929	0.714	0.571	0.357	0.214	
5.3	0.923	0.692	0.538	0.308	0.154	
5.4	0.917	0.667	0.500	0.250	0.083	
5.5	0.909	0.636	0.455	0.182	0	
5.6	0.900	0.600	0.400	0.100		
5.7	0.889	0.555	0.333	0		
5.8	0.875	0.500	0.250			
5.9	0.857	0.428	0.143			
6.0	0.833	0.333	0			
6.1	0.800	0.200				
6.2	0.750	0				
6.3	0.667					
6.4	0.500					
6.5	0					

* The factors in this table are derived from this formula:

FACTOR = (*target pH* – *current pH*) ÷ (6.6 – *current pH*)

The lime requirement (LR) in U.S. tons per acre = (*acidity* × *FACTOR) – residual credit*. *Residual credit* = 8% per month for MIN soils and 16% per month for M-O and ORG soils. **Example:** If *soil pH* = 5.0; *desired pH* = 6.0; *acidity* = 1.2; and *residual credit* = 0, then *LR* = (1.2 × 0.625) – 0 = 0.76 tons/acre. *Acidity* is calculated from the formula: (6.6 – *pH*) × 4 = *meq Ac*/100 cm^3.

Table 2.2 Target pH based on soil class

Soil Class	pH
Mineral (MIN)	6.0 *
Mineral-Organic (M-O)	5.5
Organic (ORG)	5.0

* Some crops grown on mineral soils require a target pH of 6.5. See Table 2.3 for the target pH of a specific crop.

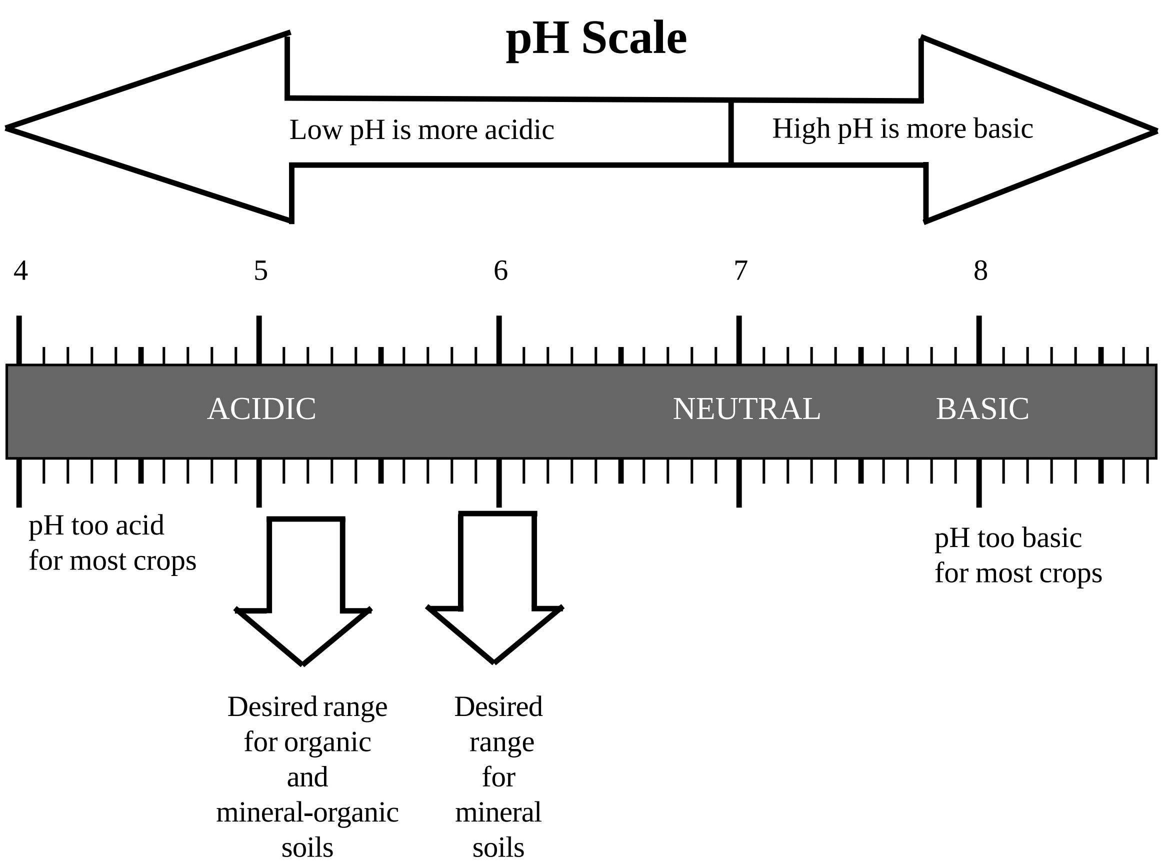


Figure 2.1 Diagram of the pH scale for agricultural soils.

Table 2.3 Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
Christmas Trees									
Blue spruce/Red cedar	6.5	100–120	6	8	$	$	–	B$	5
Fir/N Spruce/Hemlock,									
establishment	5.8	100–120	6	8	$	$	–	B$	5
maintenance	5.5	100–120	6	8	$	$	–	B$	5
Leyland cypress	6.0	100–120	6	8	$	$	_	B$	5
Line out/Seed beds	5.8	2.5 §	23	25	$	$	–	B$	5
Pine, white or Virginia	5.5	100–120	14	13	$	$	–	B$	5
Field Crops									
Corn, grain	6.0	120–160	15(16)	14	R	R	–	BR	3
Corn, silage	6.0	180–220	14(16)	9	R	R	–	BR	3
Cotton	6.2	50–70	15	13	R	R	1.0	BR	3
Kenaf	6.0	120–160	15(16)	14	R	R	–	BR	3
Milo (grain sorghum)	6.0	80–100	15(16)	14	R	R	–	B$	3
Peanut	6.0	0	18	15	$	$	0.5	AR	3
Small grain	6.0	80–100	15(16)	14	R	$	–	AR	3
Small grain/Soybean (DC)	6.0	80–100	11(15)	8	R	R	–	AR	3
Small grain silage/Soybean	6.0	80–100	13	8	R	R	–	AR	3

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
Small grain silage/Corn silage									
	6.0	80–100	13	8	R	R	–	AR	3
Soybean	6.0	0	15(16)	14	R	R	–	AR	3
Sunflower	6.0	80–100	15	14	$	R	–	B$	3
Tobacco,									
burley	6.0	150–200	12	3	$	R	–	AR	1
flue-cured	6.0	50–80	17	9	$	R	–	AR	1
greenhouse	See Note 9		25	25	$	$	–	B$	9
FORAGES									
Alfalfa									
establishment	6.5	10–30	7	9	$	$	3.0	B$	12
maintenance	6.5	0	14	10	$	$	2.0	B$	12
Common bermuda/Bahia									
	6.0	100–150	14	14	$	$	–	B$	12
Bermuda pasture									
establishment	6.5	60–80	14	14	$	$	–	B$	12
maintenance	6.5	180–220	15	7	$	$	–	B$	12

* This target pH applies to mineral soils only.

§ For nitrogen, units are lb/acre, unless a § symbol follows the number, in which case units are lb/1000 ft^2.

† These numbers refer to the equations that should be used to calculate amounts of P_2O_5 and K_2O needed. If the crop is growing in organic soil, use the equation number in parentheses. Equations are given in Table 2.4.

‡ For copper and zinc, "R" stands for "rate" in lb/acre. For copper, the rates are 2 lb/acre for mineral soils, 4 for mineral-organic, and 6 for organic soils. For zinc, the rates are 6 lb/acre, if broadcast, and 3 lb/acre if banded. The "$" indicates that the need for copper or zinc is less certain and refers you to the *$ Note: Secondary Nutrients and Micronutrients*.

¶ For boron, rates are given in lb/acre.

¥ For manganese, "A" and "B" refer to the equations for calculating the manganese availability index:

Equation A. Mn-AI = 101.2 + (0.6 × Mn-I) – (15.2 × pH).

Equation B. Mn-AI = 108.2 + (0.6 × Mn-I) – (15.2 × pH).

"R" refers to the "rate" of 10 lb/acre; "$" refers to the *$ Note: Secondary Nutrients and Micronutrients*.

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
Bluegrass	6.0	100–120	15	14	$	$	–	B$	12
Bluegrass/White clover									
	6.0	0	15	14	$	$	–	B$	12
Clover, Grass									
establishment	6.5	10–30	7	7	$	$	–	B$	12
maintenance	6.5	0	14	9	$	$	–	B$	12
Fescue/Orchard/Timothy									
establishment	6.5	50–70	14	18	$	$	–	B$	12
maintenance	6.0	100–200	15	14	$	$	–	B$	12
Gamagrass	6.0	180–220	15	14	$	$	–	A$	12
Legumes, misc.	6.0	0	20	19	$	$	–	B$	12
Prairiegrass	6.0	120–200	18	15	$	$	–	A$	12
Sudangrass/Sorghum/Millet/Red crabgrass									
	6.0	140–180	15(16)	9	$	$	–	B$	12
Sudangrass/Sorghum silage									
	6.0	180–220	14(16)	9	$	$	–	B$	12
Switchgrass	5.5	120–160	18	15	$	$	–	B$	12

LAWNS & GARDENS

Crop	Target pH	
Azalea	5.0	Refer to Note #4 and Special Printout A
Berries/Fruit/Nuts	6.0	Refer to Note #18 and Special Printout A
Camellia	5.0	Refer to Note #4 and Special Printout A
Centipede grass	5.5	Refer to Note #4 and Special Printout B
Flower garden	6.0	Refer to Note #4 and Special Printout A
Lawn	6.0	Refer to Note #4 and Special Printout A

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
Mountain laurel	5.0	Refer to Note #4 and Special Printout A							
Rhododendron	5.0	Refer to Note #4 and Special Printout A							
Rose	6.5	Refer to Note #4 and Special Printout A							
Shrubbery	6.0	Refer to Note #4 and Special Printout A							
Trees, shade	6.0	Refer to Note #4 and Special Printout A							
Vegetable garden	6.5	Refer to Note #4 and Special Printout A							
NURSERY, COMMERCIAL									
Dahlia	6.0	50–70	15	14	$	$	–	B$	
Flowers									
bulbs	6.0	50–70	15	14	$	$	–	B$	
roots	6.0	50–70	15	14	$	$	–	B$	
Gladiolus	6.0	50–70	15	14	$	$	2.0	B$	
Greenhouse		See Note 9	25	25	$	$	–	B$	9
Gypsophila	6.5	50–70	15	14	$	$	–	B$	

* This target pH applies to mineral soils only.

§ For nitrogen, units are lb/acre, unless a § symbol follows the number, in which case units are lb/1000 ft^2.

† These numbers refer to the equations that should be used to calculate amounts of P_2O_5 and K_2O needed. If the crop is growing in organic soil, use the equation number in parentheses. Equations are given in Table 2.4.

‡ For copper and zinc, "R" stands for "rate" in lb/acre. For copper, the rates are 2 lb/acre for mineral soils, 4 for mineral-organic, and 6 for organic soils. For zinc, the rates are 6 lb/acre, if broadcast, and 3 lb/acre if banded. The "$" indicates that the need for copper or zinc is less certain and refers you to the *$ Note: Secondary Nutrients and Micronutrients*.

¶ For boron, rates are given in lb/acre.

¥ For manganese, "A" and "B" refer to the equations for calculating the manganese availability index:

Equation A. Mn-AI = 101.2 + (0.6 × Mn-I) – (15.2 × pH).

Equation B. Mn-AI = 108.2 + (0.6 × Mn-I) – (15.2 × pH).

"R" refers to the "rate" of 10 lb/acre; "$" refers to the *$ Note: Secondary Nutrients and Micronutrients*.

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
Nursery									
Container stock		See Note 11	25	25	$	$	–	B$	11
Trees		See Note 11	5	8	$	$	–	B$	11
Rhododendron/Ginseng/Native ornamentals									
	5.0	1 §	23	25	$	$	–	B$	4
ORCHARD/ FRUIT & NUT TREES									
Apple									
establishment	6.5	See Note 16	15	16	$	$	–	–	16
maintenance	6.0	See Note 16	18	16	$	$	–	–	16
Peach									
establishment	6.5	See Note 17	15	16	$	$	–	–	17
maintenance	6.2	See Note 17	18	16	$	$	–	–	17
Pecan									
establishment	6.0	See Note 15	15	16	$	$	–	–	15
maintenance	6.0	See Note 15	18	16	$	$	–	–	15
FOREST TREES & SEED									
Hardwood									
establishment	5.5	0	20	19	$	$	–	–	11
maintenance	5.5	80–120	20	20	$	$	–	–	11
Pine									
establishment	5.5	0	20	20	$	$	–	–	11
maintenance	5.5	100–150	20	20	$	$	–	–	11
nursery	5.5	140–160	18	18	$	$	–	–	11
Trees from seed									
hardwoods	6.0	120–160	18	19	$	$	–	–	11
fir/spruce	5.5	120–160	18	19	$	$	–	–	11
pine	5.5	120–160	18	19	$	$	–	–	11

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
TURF/ GOLF GREENS									
Fairway/Athletic turf	6.2	See Note 14	11	8	$	$	–	$	14
Tee	6.2	See Note 14	25	24	$	$	–	$	14
Greens	6.2	See Note 14	25	24	$	$	–	$	14
VEGETABLES & SMALL FRUITS									
Asparagus									
establishment	6.5	60–80	7	14	$	$	–	B$	6
maintenance	6.0	80–100	18	7	$	$	–	B$	6
Beans/Peas	6.0	80–100	5	7	$	$	–	A$	6
Beets	6.0	100–120	7	7	$	$	–	B$	6
Blueberry									
establishment	–	10–30	17	16	$	$	–	B$	18
maintenance	–	30–60	18	16	$	$	–	B$	18
Broccoli/Brussels sprouts/Cauliflower	6.0	80–100	4	7	$	$	2.0	A$	6

* This target pH applies to mineral soils only.

§ For nitrogen, units are lb/acre, unless a § symbol follows the number, in which case units are lb/1000 ft^2.

† These numbers refer to the equations that should be used to calculate amounts of P_2O_5 and K_2O needed. If the crop is growing in organic soil, use the equation number in parentheses. Equations are given in Table 2.4.

‡ For copper and zinc, "R" stands for "rate" in lb/acre. For copper, the rates are 2 lb/acre for mineral soils, 4 for mineral-organic, and 6 for organic soils. For zinc, the rates are 6 lb/acre, if broadcast, and 3 lb/acre if banded. The "$" indicates that the need for copper or zinc is less certain and refers you to the *$ Note: Secondary Nutrients and Micronutrients*.

¶ For boron, rates are given in lb/acre.

¥ For manganese, "A" and "B" refer to the equations for calculating the manganese availability index:

Equation A. Mn-AI = 101.2 + (0.6 × Mn-I) – (15.2 × pH).

Equation B. Mn-AI = 108.2 + (0.6 × Mn-I) – (15.2 × pH).

"R" refers to the "rate" of 10 lb/acre; "$" refers to the *$ Note: Secondary Nutrients and Micronutrients*.

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
Cabbage	6.0	80–100	4	7	$	$	2.0	A$	6
Cantaloupe/Watermelon	6.0	60–80	11	7	$	$	1.0	A$	6
Corn, sweet	6.0	140–180	15	13	$	$	–	BR	6
Cucumbers	6.0	80–140	12	7	$	$	–	A$	6
Grape									
establishment	6.0	See Note 18	15	13	$	$	–	B$	18
maintenance	6.0	See Note 18	18	13	$	$	0.5	B$	18
Kale/Mustard/Spinach	6.0	100–120	7	7	$	$	–	A$	6
Okra	6.0	80–100	7	7	$	$	0.5	B$	6
Pea, southern	6.0	10–30	15	14	$	$	–	A$	6
Pepper	6.0	80–100	5	5	$	$	1.0	A$	6
Plant bed crops	6.0		See Special Printout A						6
Potato, Irish	6.0	100–150	4	5	$	$	–	B$	6
Radish	6.0	80–100	7	7	$	$	2.0	A$	6
Rape/Canola	6.0	120–140	15	14	$	$	2.0	B$	6
Raspberry/Blackberry									
establishment	6.0	30–60	10	18	$	$	–	B$	18
maintenance	6.0	80–100	18	18	$	$	–	B$	18
Squash/Pumpkin	6.0	90–120	11	7	$	$	–	A$	6
Strawberry									
establishment	6.0	30–60	15	13	$	$	1.0	A$	18
maintenance	6.0	60–80	18	18	$	$	1.0	A$	18

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
Sweetpotato	6.0	60–90	11	8	$	$	0.5	B$	6
Tomato									
field	6.5	90–120	5	4	$	$	–	A$	7
greenhouse	–	See Note 9	25	25	$	$	–	B$	9
Turnip	6.0	100–120	7	7	$	$	2.0	A$	6
Vegetables, other	6.0	80–100	7	7	$	$	–	A$	6
ROADSIDE AREAS									
Critical area	6.0	40–60	16	20	$	$	–	B$	–
Roadside grass									
establishment	5.8	40–60	16	18	$	$	–	B$	–
maintenance	5.8	70–90	20	20	$	$	–	B$	–

* This target pH applies to mineral soils only.

§ For nitrogen, units are lb/acre, unless a § symbol follows the number, in which case units are lb/1000 ft^2.

† These numbers refer to the equations that should be used to calculate amounts of P_2O_5 and K_2O needed. If the crop is growing in organic soil, use the equation number in parentheses. Equations are given in Table 2.4.

‡ For copper and zinc, "R" stands for "rate" in lb/acre. For copper, the rates are 2 lb/acre for mineral soils, 4 for mineral-organic, and 6 for organic soils. For zinc, the rates are 6 lb/acre, if broadcast, and 3 lb/acre if banded. The "$" indicates that the need for copper or zinc is less certain and refers you to the *$ Note: Secondary Nutrients and Micronutrients*.

¶ For boron, rates are given in lb/acre.

¥ For manganese, "A" and "B" refer to the equations for calculating the manganese availability index:

Equation A. Mn-AI = 101.2 + (0.6 × Mn-I) – (15.2 × pH).

Equation B. Mn-AI = 108.2 + (0.6 × Mn-I) – (15.2 × pH).

"R" refers to the "rate" of 10 lb/acre; "$" refers to the *$ Note: Secondary Nutrients and Micronutrients*.

Table 2.3 (cont.) Information required to calculate lime and fertilizer rates

Crop	Target pH *	N§	P_2O_5†	K_2O†	Cu‡	Zn‡	B¶	Mn¥	Refer to Note
WILDLIFE AREAS & FOOD PLOTS									
Deer/Turkey	6.0	0–60	14(18)	14	$	$	–	B$	NA
Fish Pond	6.5			Not applicable					
Upland Game	6.0	0–60	14(18)	14	$	$	–	B$	NA
Waterfowl	6.0	0–60	14(18)	14	$	$	–	B$	NA

* This target pH applies to mineral soils only.

§ For nitrogen, units are lb/acre, unless a § symbol follows the number, in which case units are lb/1000 ft^2.

† These numbers refer to the equations that should be used to calculate amounts of P_2O_5 and K_2O needed. If the crop is growing in organic soil, use the equation number in parentheses. Equations are given in Table 2.4.

‡ For copper and zinc, "R" stands for "rate" in lb/acre. For copper, the rates are 2 lb/acre for mineral soils, 4 for mineral-organic, and 6 for organic soils. For zinc, the rates are 6 lb/acre, if broadcast, and 3 lb/acre if banded. The "$" indicates that the need for copper or zinc is less certain and refers you to the *$ Note: Secondary Nutrients and Micronutrients*.

¶ For boron, rates are given in lb/acre.

¥ For manganese, "A" and "B" refer to the equations for calculating the manganese availability index:

Equation A. Mn-AI = 101.2 + (0.6 × Mn-I) – (15.2 × pH).

Equation B. Mn-AI = 108.2 + (0.6 × Mn-I) – (15.2 × pH).

"R" refers to the "rate" of 10 lb/acre; "$" refers to the *$ Note: Secondary Nutrients and Micronutrients*.

Phosphate (P_2O_5) & Potash (K_2O)

The P_2O_5 and K_2O recommendations shown on the soil test report come from the equations shown in Table 2.4. The P-I or K-I value is inserted into the equation, and the results are rounded to the nearest 10 lb for field crops and to the nearest 0.5 lb for greenhouse, golf tees and golf greens. Recommendations for field crops show a range of 20 lb/acre. Rates of P_2O_5 and K_2O (lb/acre), based on soil test index value and equation, appear in Table 2.5.

Calcium (Ca)

The soil test report does not contain a space for a calcium recommendation. Lime, which contains calcium carbonate ($CaCO_3$), provides the crop with this nutrient. Because calcium is supplied

Table 2.4 Equations for calculating rates of P_2O_5 and K_2O*

1	$0.0467\ I^2 - 13.0\ I + 900$ = lb/acre
2	$0.0202\ I^2 - 6.37\ I + 500$ = lb/acre
3	$0.0100\ I^2 - 3.50\ I + 300$ = lb/acre
4	$0.0175\ I^2 - 4.46\ I + 300$ = lb/acre
5	$0.0193\ I^2 - 4.90\ I + 300$ = lb/acre
6	$0.0272\ I^2 - 6.08\ I + 300$ = lb/acre
7	$0.0100\ I^2 - 3.25\ I + 250$ = lb/acre
8	$0.0173\ I^2 - 4.64\ I + 250$ = lb/acre
9	$0.0102\ I^2 - 3.00\ I + 220$ = lb/acre
10	$0.0103\ I^2 - 2.90\ I + 200$ = lb/acre
11	$0.0190\ I^2 - 4.20\ I + 200$ = lb/acre
12	$0.0053\ I^2 - 2.00\ I + 180$ = lb/acre
13	$0.0120\ I^2 - 2.90\ I + 165$ = lb/acre
14	$0.0116\ I^2 - 2.75\ I + 150$ = lb/acre
15	$0.0140\ I^2 - 3.20\ I + 150$ = lb/acre
16	$0.0227\ I^2 - 4.42\ I + 150$ = lb/acre
17	$0.0084\ I^2 - 2.19\ I + 140$ = lb/acre
18	$0.0120\ I^2 - 3.00\ I + 120$ = lb/acre
19	$0.0044\ I^2 - 1.60\ I + 100$ = lb/acre
20	$0.0120\ I^2 - 2.40\ I + 80$ = lb/acre
21	$0.0012\ I^2 - 0.315\ I + 20$ = lb/1000 ft^2
22	$0.0005\ I^2 - 0.418\ I + 11$ = lb/1000 ft^2
23	$0.0005\ I^2 - 0.135\ I + 9$ = lb/1000 ft^2
24	$0.0007\ I^2 - 0.160\ I + 8$ = lb/1000 ft^2
25	$0.0005\ I^2 - 0.130\ I + 6.5$ = lb/1000 ft^2

* Refer to Table 2.3 to match the appropriate equation with the desired crop. Insert the current soil test index value (I) into the equation and solve for the suggested fertilizer rates. The rate of fertilizer suggested ranges 10 lb above and below the calculated value. The results of the above equations for specific soil test indices are shown in Table 2.5.

Table 2.5 Rates of P_2O_5 or K_2O to apply based on soil test index value and crop-specific equation. *

Eq.	Soil Test Index															
#	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
1	900	780	660	550	460	370	290	220	160	110	70	40	10	0		
2	500	440	380	330	280	230	190	150	120	90	70	40	30	10	0	0
3	300	270	230	200	180	150	130	100	80	70	50	40	20	10	10	
4	300	260	220	180	150	120	100	70	60	40	30	20	20	20	20	10–30
5	300	250	210	170	130	100	80	50	30	20	0					
6	300	240	190	140	100	60	30	10	0							
7	250	220	190	160	140	110	90	70	50	40	30	10	0			
8	250	210	160	130	90	60	30	10	0							
9	220	190	160	140	120	100	80	60	50	30	20	10	10	0		
10	200	170	150	120	100	80	60	50	30	20	10	10	0			
11	200	160	120	90	60	40	20	0								
12	180	160	140	130	110	90	80	70	50	40	30	20	20	10	0	
13	165	140	110	90	70	50	30	20	10	0						
14	150	120	100	80	60	40	30	10	0							
15	150	120	90	70	40	30	10	0								
16	150	110	70	40	10	0										
17	140	120	100	80	70	50	40	30	20	10	10	0				
18	120	90	60	40	20	0										
19	100	80	70	60	40	30	20	10	0							
20	80	60	40	20	0											
21	20.0	17.0	14.0	11.5	9.5	7.5	5.5	4.0	2.5	1.5	0.5	0				
22	11.0	9.5	8.0	7.0	6.0	5.0	4.0	3.0	2.5	2.0	1.0	1.0	0.5	0		
23	9.0	7.5	6.5	5.5	4.5	3.5	2.5	2.0	1.5	1.0	0.5	0				
24	8.0	6.5	5.0	4.0	2.5	2.0	1.0	0								
25	6.5	5.0	4.0	3.0	2.0	1.0	0.5	0								

*Rates given for equations 1 through 20 are rounded to the nearest 10 lb/acre, and those for equations 21 through 25 to the nearest 0.5 lb per 1000 ft^2.

during the liming process, supplemental calcium is rarely needed.

Magnesium (Mg)

If a soil needs magnesium, this nutrient can be supplied through liming in much the same way that calcium can. Dolomitic limestone is a mixture of calcium and magnesium carbonates [$CaMg(CO_3)_2$] and contains at least 120 lb Mg per ton. On soils where magnesium levels are difficult to maintain, application of dolomitic lime should provide an adequate amount.

To evaluate the magnesium status of the soil, multiply Mg% by the CEC.

- If this value is greater than or equal to 0.5 meq, no magnesium is needed.
- If this value is less than 0.5 meq and less than 10% of the CEC, a dollar sign (*$*) will appear in the *Mg* column of the *Recommendations* section. The *$* symbol refers the grower to *$ Note: Secondary Nutrients and Micronutrients*, which is included with the soil test report.
- If this value is less than 0.5 meq but greater than 0.25 meq and greater than 10% of the CEC, no magnesium is needed.
- If magnesium is less than 0.25 meq, a *$* symbol will appear in the *Mg* column on the report, regardless of the Mg%.

The *$ Note* in Part III of this booklet gives additional information on fertilizing with magnesium.

Manganese (Mn)

Ten pounds of manganese per acre is recommended when the manganese availability index (Mn-AI) is less than 25 and the crop is known to respond well to manganese (Table 1.2). For crops where response to manganese is less certain (Table 1.3), a *$* symbol refers the grower to the *$ Note* flyer entitled *Secondary Nutrients and Micronutrients*. When the Mn-AI is less than 25 and the soil pH is 6.2 or greater, *$pH* appears in the *Mn* column. This designation indicates that high pH is responsible for the manganese deficiency and refers the grower back to the *$ Note* for several treatment options.

Zinc (Zn)

When the zinc availability index (Zn-AI) is greater than 25, no addition of zinc is necessary. A rate of 6 lb/acre is appropriate if the Zn-AI is 25 or less and the crop is known to be responsive to zinc. When crop response to zinc is less certain, the recommendation will be flagged with a *$* symbol, refering the grower to the *$ Note*.

Copper (Cu)

The need for copper fertilization depends on the copper index (Cu-I), the crop and the soil type. A Cu-I of 25 or less, for a crop known to respond to copper, indicates that copper is needed. Recommended rates depend on soil type: 2 lb of copper per acre for mineral soils, 4 for mineral-organic soils and 6 for organic soils.

If a *$* notation appears in the *Cu* column of the *Recommendations* section for a first crop, it indicates that the crop's response to the addition of copper is uncertain. If this notation is for a second crop, it indicates that copper may be needed if it was not applied to the first crop as recommended. The crops listed in Table 2.3 have an *R* in the Cu column if they respond well to copper fertilization. The *$ Note* in Part III of this booklet gives additional information on fertilizing with copper.

Boron (B)

Even though there is no test to assess boron levels in soil, soil test reports may include boron recommendations for certain crops. Rates given are based on field observations and experiments. Crop response to these levels has been proven. However, too much boron can be toxic to plants.

Sulfur (S)

As mentioned in Part I, sulfur leaches readily on sandy soils and accumulates in the subsoil. Recommendations for this nutrient vary with soil type and rainfall. If the S-I of deep sandy soils is less than 25, fertilization with sulfur is probably necessary. The general rate for sulfur application is 20–25 lb/acre. Sulfur is rarely lacking in piedmont or mountain soils due to their high clay content. Under normal growing conditions, sulfur is generally sufficient on organic soils as well.

Because sulfur is so mobile in the soil, plant tissue analysis is the best way to gauge sufficiency. The deficiency symptoms for sulfur and nitrogen are very similar. Likewise, soil conditions that cause nitrogen to leach also have the same effect on sulfur.

Sulfur deficiency commonly occurs on deep, sandy, coastal plain soils. These soils are often low in organic matter and have a clay layer 15 inches or more below the surface. Sulfur deficiency can occur when the clay layer is closer to the surface on shallow-rooted crops such as small grains. Corn, coastal bermudagrass and tobacco are also particularly susceptible to sulfur deficiency. Most dry-blend tobacco fertilizers supply adequate sulfur for the current growing season.

Part III. Notes for Specific Crops / Situations

Special Printout Groups

Two plant groups require lime and fertilizer recommendations that are appropriate for application to relatively small areas. These special printout groups are

A. Lawns, Gardens and Ornamentals, and
B. Centipedegrass.

For both of these groups, lime and fertilizer recommendations are expressed as pounds per 1000 ft^2, as shown in Table 3.1.

The potassium index (*K-I*) and the phosphorus index (*P-I*) determine the fertilizer grade recommended. For special printout group A, the amount of fertilizer recommended supplies 1.0 lb of nitrogen per 1000 ft^2. For special printout group B, the rate is 0.5 lb of nitrogen per 1000 ft^2. *Note 4: Fertilization of Lawns, Gardens and Ornamentals* provides additional information regarding supplemental nitrogen rates and time of application.

Table 3.1 Recommended fertilizer rates (lb/1000 ft^2) for lawns and ornamentals.

Phosphorus Index (P-I)	Potassium Index (K-I)	Lawns/Gardens/Ornamentals Grade	Rate	Centipedegrass Grade	Rate
<25	<25	5-10-10	20	3-9-9	16
<25	>25 to 50	5-10-10	20	5-10-10	10
<25	>50	5-10-5	20	5-10-10	10
>25 to 50	<25	6-6-18	17	5-5-15	10
>25 to 50	>25 to 50	10-10-10	10	5-5-15	10
>25 to 50	>50	5-10-5	20	N only	0.5
>50	<25	8-0-24	12.5	8-0-24	6
>50	>25 to 50	15-0-14	7	15-0-14	3
>50	>50	N only	1	N only	0.5

$ NOTE: Secondary Nutrients & Micronutrients (February 2007)

This note gives advice for eliminating or preventing specific soil fertility problems. The $ on your soil test report indicates actual or potential deficiencies of magnesium, copper, zinc and/or manganese. Additionally, potential toxicities are noted for copper and zinc at certain soil test levels. Recommendation codes for each of these elements are explained below.

Magnesium (Mg) Recommendation

0 Additional Mg is not needed.

$ Mg levels in the soil are low.
• If lime is recommended, use dolomitic lime, which contains a minimum of 120 lb Mg per ton. Dolomitic lime is the most economical source of Mg.
• If no lime is needed, add 20–30 lb/acre of readily soluble Mg to your fertilizer. Annual applications of Mg may be required until subsequent soil tests show adequate levels in the soil.

Copper (Cu) Recommendation

0 Additional Cu is not needed.

Any number other than 0
This number is a suggested application rate for Cu, expressed in lb/acre. In this case, the Cu index (*Cu-I*) is low (< 25), and the crop will respond to Cu fertilization. Applying the suggested rate should correct the deficiency for several years. Incorporate broadcast applications into the plow layer for maximum benefit. Foliar application is effective if the Cu deficiency occurs during the growing season as determined by tissue testing.

Table 1. Micronutrient application rates (lb element per acre) *

	Banded		Broadcast			Foliar Spray		
Soil Class	Mn	Zn	Mn	Zn	Cu	Mn	Zn	Cu
MIN	3	3	10	6	2	0.5	0.5	0.25
M-O	3	3	10	6	4	0.5	0.5	0.25
ORG	3	3	10	6	6	0.5	0.5	0.25

* Once a micronutrient need has been established by soil testing, a choice of the material to use must be made. Under the soil and climatic conditions in North Carolina, sulfates of the particular element and liquids formulated with ammonia, chlorides and nitrates are the most effective. Chelates and organic complexes used at equivalent elemental rates of the materials listed above are effective, but quite expensive. Oxides and most oxysulfates, except under special conditions, are not effective.

Premium fertilizers, which contain an array of micronutrients in very small quantities, may not correct a deficiency.

$ Monitor Cu levels in your crop. *Cu-I* is low (< 25), but the indicated crop may not respond to Cu fertilization. If an application rate is given for *1st Crop*, a *$* in the *Cu* column for *2nd Crop* reminds you that the second crop may still need Cu if it was not applied to the first crop.

C The *Cu-I* is greater than 2000. The critical toxic level is 3000. See the narrative printed on the soil test report for further advice.

Zinc (Zn) Recommendation

0 Additional Zn is not needed.

Any number other than 0
This number is a suggested application rate for Zn, expressed in lb/acre. In this case, the Zn-availability index (*Zn-AI*) is low (< 25), and the crop indicated will respond to Zn. The recommended amount should correct the deficiency for several years.

$ Monitor Zn levels in your crop. The *Zn-AI* is low (< 25), but the indicated crop may not respond to Zn fertilization. If an application rate is given for *1st Crop*, a *$* in the *Zn* column for *2nd Crop* reminds you that the second crop may still need Zn if it was not applied to the first crop.

Z The *Zn-I* is greater than 2000. The critical toxic level is 3000. See the narrative printed on the soil test report for further advice.

Peanuts are very sensitive to Zn, and toxicity may occur at soil levels well below 2000. The risk of toxicity is greater with low soil pH and has been seen at a *Zn-AI* as low as 300. A critical toxic level has been set at 500 for peanuts.

The *Zn-AI* is an availability index related to soil class. The *Zn-AI* will be greater than the *Zn-I* for mineral-organic (M-O) and organic (ORG) soils due to a lower target pH for these soil classes.

When Zn deficiencies occur due to high pH and phosphorus levels, a foliar application of Zn is required. The decision to apply Zn in this manner should be based on current soil tests and plant analyses. Some limestone sources contain enough Zn to build soil test levels above the critical point.

Manganese (Mn) Recommendation

0 Additional Mn is not needed.

10 Apply Mn at a rate of 10 lb/acre broadcast. The Mn-availability index (*Mn-AI*) is low (< 25), and the indicated crop is known to respond to Mn application.

$ Monitor your crop closely for Mn problems. In this case, the *Mn-I* < 25, but the crop indicated may not respond to addition of Mn. Monitoring the crop through plant tissue analysis is a good way to track Mn levels in the crop. If tissue levels are low, application of foliar Mn may be warranted.

$pH There is an existing or potential Mn deficiency due to *pH* > 6.2 and *Mn-AI* < 25. The recommendations outlined here can correct or prevent this problem:

- For currently growing crops, apply a totally water-soluble source of Mn to the foliage. Depending on the severity of the deficiency and the crop's stage of growth, a second application may be required.

- Under preplant conditions and with *Mn-I* > 25, band acid-forming starter fertilizers that do not contain Mn. If *Mn-I* < 25, use an acid-forming starter fertilizer containing Mn.

- If *pH* > 6.2, do not soil-broadcast a Mn fertilizer. If overliming is the principal cause of Mn deficiency, apply acid-forming fertilizers or till deeply to lower the soil pH. Foliar applications and/or acid-banded treatments are remedial and may be required for each crop until the pH falls below 6.2.

pH$ Mn levels are high (*Mn-AI* > 25), but there is potential for deficiency since soil pH is also high (> 6.4). Use a foliar spray of Mn fertilizer to correct a deficiency if it occurs.

Mn deficiency is commonly observed throughout the coastal plain. It can be due to either overliming (*pH* > 6.2) or inherently low levels of soil Mn. Although less frequently observed, Mn deficiencies can also occur in piedmont and mountain regions.

Mn availability is influenced by soil pH. As pH increases, Mn availability decreases. Some crops show Mn deficiency much more readily than others.

On the soil test report, three values relate to Mn levels: *Mn-I*, an index correlated with the actual amount of manganese in the soil; *Mn-AI(1)*, the Mn-availability index for the first crop; and *Mn-AI(2)*, the Mn-availability index for the second crop.

NOTE 1: Fertilization of Tobacco (revised January 2006)

Historically, tobacco has been a heavily fertilized crop. Fertilizer recommendations on the soil test report produce high-yielding, quality tobacco assuming other limitations are negligible. The plant's ability to use nutrients depends on adequate lime having been applied, the method and timing of fertilization, variety selection and nematode management practices. Low yields and poor quality are seldom related to soil fertility alone.

Lime

The rate of lime recommended on the soil test report

- raises soil pH and maintains it between 5.8 and 6.2;
- supplies the essential nutrients calcium and magnesium;
- neutralizes aluminum, which becomes toxic to plant roots when the soil pH is too low; and
- enhances uptake and use of phosphorus.

Magnesium (Mg) & Sulfur (S)

Magnesium deficiency is typically seen on light-colored, sandy soils, often in seasons of high rainfall. Due to this fact, this condition is also known as "sand drown." Symptoms are seen as yellowing between veins on the lower leaves (interveinal chlorosis) that may progress midway up the stalk. The yellowing often begins at the tip or along leaf margins, progressing to the leaf's base and center. Tissue may appear white in extreme cases.

If there is a $ symbol in the *Mg* column on the soil test report, then magnesium levels are low. If lime is needed, apply dolomitic lime since it will supply 120 lb Mg per ton. If lime is not recommended, apply a readily available source of magnesium at a rate of 20 to 30 lb/acre. Sulfate of potash-magnesia (0-0-22, 11.5% Mg) alone or in a blend is a good source of magnesium.

Sulfur is recommended for tobacco when the index (S-I) is 25 or lower. Tobacco often exhibits sulfur deficiency (general yellow color of whole plant) before lay-by. The crop may grow out of it later if roots reach the subsoil where sulfur accumulates. Crops growing on deep sandy soils where clay is 16 inches or more below the surface are especially vulnerable to sulfur deficiency.

Complete fertilizers may or may not contain sulfur. Good sources include 0-0-22 (23% S), 0-0-50 (18% S), or 24-S nitrogen solutions (3% by weight). Typically, applying sulfur at a rate of about 20 lb/acre will correct deficiencies.

Manganese (Mn)

Manganese deficiency can occur on sandy coastal plain soils when the pH is 6.2 or higher. The visual symptoms mimic closely those of weather fleck but are usually more severe. Small white flecks or lesions develop on lower leaves, and with time, the flecks turn brown. As the deficiency progresses, the flecks often join together resulting in dead tissue falling out of the leaf structure. In contrast to weather fleck, Mn-deficient plants are also stunted and have a slightly yellow color.

If *$pH* appears in the manganese availability-index (*Mn-AI*) column of the *Recommendations* section on the soil test report, there is a potential for Mn deficiency. This designation indicates that overliming is the principal cause of the deficiency. The *$ Note*, which accompanies the report, provides options to correct this problem.

When *Mn-AI* is 25 or lower and *pH* is below 6.2, the rate *10 lb/acre* appears in the *Mn* column of the *Recommendations* section. Manganese deficiency seldom occurs on piedmont or mountain soils. In these areas, toxicity is a more likely problem and is generally prevented by maintaining the soil pH near 6.0.

Zinc (Zn) and Copper (Cu)

Zinc and copper deficiencies have not been confirmed for tobacco. However, if the zinc index (*Zn-I*) or copper index (*Cu-I*) is below 25, a *$* symbol appears in the *Zn* or *Cu* column of the *Recommendations* section. Refer to the *$ Note* for application rates and methods if you wish to increase the levels of these nutrients in the soil.

Nitrogen (N) for Flue-Cured Tobacco

NCDA&CS soil test reports recommend a rate of 50 to 80 lb/acre based on a wide variety of soil and climatic conditions. This range represents the total nitrogen requirement (preplant and sidedress) and has been satisfactory in on-farm tests.

Rates of nitrogen are adjustable for each field, depending on depth of subsoil:

- where depth to subsoil is less than 5 inches, apply 50 lb/acre; and
- for each additional inch beyond 5 inches, apply 10 lb/acre until a maximum of 80 lb/acre is reached.

A nitrogen rate that exceeds recommendations can delay maturity and/or cause curing problems. Never apply more than 40 lb/acre at planting. Sidedress the remainder at lay-by.

Because of potential nitrogen problems, planting tobacco behind legumes or after recent application of farm manures is not recommended. However, the following guidelines may be helpful in situations where this practice is necessary:

- reduce the nitrogen rate by 15 to 20 lb/acre (potentially less on sandy soils) following legume crops;
- consider soil type and yield to evaluate nitrogen reductions following corn crops;
- reduce the nitrogen rate by 30 lb/acre for each ton of poultry litter applied; or
- reduce the nitrogen rate by 10 to 15 lb/acre for each ton of cattle manure applied.

Growers should certainly evaluate nitrogen sources based on handling and cost per pound. Liquid nitrogen products such as 24-S or 30% UAN solutions are less expensive. University tests with these fertilizers have shown no adverse effects on yield or quality when they are applied correctly. These materials should be knifed in or covered to prevent volatilization potential. Accurate calibration is especially important since these products or mixes are highly concentrated.

Nitrogen (N) for Burley Tobacco

NCDA&CS soil test reports recommend a nitrogen rate of 150 to 200 lb/acre based on research and on-farm tests. Soil type determines the actual rate used. The lower rate is appropriate on heavy-textured soils, particularly on sites where yields have never exceeded 2500 lb/acre.

Never exceed the higher rate on light-textured soils. Too much nitrogen causes ripening problems and reduces quality. Because of potential nitrogen problems, reduce the nitrogen rate 15 to 20 lb/acre following legumes, 30 lb/acre for each ton of poultry manure applied and 10 to 15 lb/acre for each ton of cattle manure applied.

Phosphate (P_2O_5) and Potash (K_2O) for Flue-Cured Tobacco

A good way to reduce expenses and off-site movement of phosphorus fertilizer is to apply less. About 85% of tobacco soils tested have a high to very high phosphorus index (P-I >50). On-farm tests show no benefit in yield or quality from routine application of phosphorus fertilizer to such soils. Only 15 lb of P_2O_5 is removed from the soil for each 2,500 lb of leaf harvested.

Tobacco-grade fertilizers are available without P and can be custom-blended to supply the N and K_2O recommended on the soil test report. Select a mixed fertilizer grade that will supply nitrogen at a rate of 40 lb/acre, all the recommended P_2O_5 and up to 120 lb/acre of K_2O at planting or within 10 days after setting. You can apply additional nitrogen and/or potash later as a sidedressing.

Phosphate (P_2O_5) and Potash (K_2O) for Burley Tobacco

Soils in the burley tobacco region have high levels of phosphorus and potassium. These nutrients build-up when they are applied on a continual basis at rates that exceed soil test recommendations.

In 35 to 40% of the areas where burley is grown, a P_2O_5 or K_2O rate of 40 to 50 lb/acre is sufficient. This low rate reduces fertilizer costs as well as the potential for salt injury.

P_2O_5 and K_2O recommendations are specific for the soil tested. Select a mixed fertilizer that best supplies the recommended rates of P_2O_5 and K_2O. If an appropriate mixed grade is unavailable, use single-grade materials. Ammonium nitrate (33.5% N), triple superphosphate (46% P_2O_5) and sulfate of potash (50% K_2O) are acceptable.

Tissue Testing to Ensure Quality & Yield

Tissue testing should be an integral part of tobacco production. During the growing season, it can help identify nutrient deficiencies. At the end of the season, it can be used successfully to determine ripeness and facilitate decisions on timing of flue-cured tobacco harvest.

NOTE 2: Fertilization of Tobacco Plant Beds (revised Aug 1998)

(This note will probably be discontinued.)

Lime

Any lime suggested is designed to raise the soil pH to an optimum level for plant growth. The optimum pH range for tobacco seedlings is between 5.8 and 6.2. Low soil pH values can be detrimental due to low calcium and magnesium coupled with high soil acidity. At higher soil pH values, manganese availability decreases dramatically as the pH increases above 6.2. Therefore, lime recommendations should be followed as closely as possible to stay within the desired pH range.

Lime recommendations are given in units of "M," which means lb/1000 ft^2. To convert this rate to lb/100 yd^2, multiply by 0.9: for example, 100 yd^2 = 900 ft^2. When lime is suggested, it should be applied as early as possible to allow ample time to neutralize the soil acidity. For best results, use high quality agricultural grade lime and incorporate thoroughly into the top 6 to 8 inches of soil.

Since magnesium is difficult to maintain on sandy coastal plain soils, dolomitic lime should be applied when lime is suggested. Piedmont and mountain soils generally contain sufficient magnesium to permit the use of calcitic lime.

Magnesium (Mg) is routinely tested on soil samples. When the test results show a need for magnesium, a *$* symbol will appear in the *Mg* column of the *Recommendations* section. If the *$* appears on your report and no lime is suggested, use a 12-6-6 plant bed fertilizer containing 1.0% Mg, or broadcast 5 lb of magnesium sulfate (Epsom salts) per 100 yd^2 and incorporate 2 to 3 inches into the soil.

Fertilizer Application Rates

For plant beds covered with perforated plastic, apply no more than 50 lb 12-6-6 per 100 yd^2 (2400 lb/acre) and incorporate into the top 2 to 3 inches of soil. Apply no more than 75 lb of 12-6-6 per 100 yd^2 (3600 lb/acre) on beds covered with nylon, Reemay or cotton. Higher fertilizer rates could result in poor germination and salt damage to the roots of young seedlings.

Table 1. Sample application rates of some supplemental fertilizers

			Content (lb)			
Materials	**Analysis**	**lb/100 yd^2**	**N**	**K_2O**	**Mg**	**S**
Sodium nitrate	16-0-0	3.2	0.51	–	–	–
Nitrate of Na-K	15-0-14	3.4	0.51	0.48	–	–
Calcium nitrate	15.5-0-0	3.23	0.5	–	–	–
Potassium sulfate	0-0-50; 17.6% S	1.0	–	0.50	–	0.18
Magnesium sulfate	14% S; 10% Mg	3.8	–	–	0.38	0.53
Sulfate of potash-magnesium	0-0-22 22% S; 11% Mg	2.3	–	0.51	0.25	0.51

On sites where the soil test phosphorus index (P-I) is less than 25, an additional application of 8–10 lb triple superphosphate (0-46-0) per 100 yd^2 may be beneficial. Apply this additional phosphorus along with the 12-6-6 and incorporate 2–3 inches into the soil.

Supplemental Fertilizer

Additional nitrogen (N), potassium (K) or sulfur (S) may be needed on sandy soils exposed to excess rain or irrigation. Visual diagnosis of deficiencies can be risky because the symptoms for some nutrients, such as nitrogen and sulfur, are very similar. Therefore, the need for supplemental treatments is best diagnosed by soil and plant tissue tests. Collect soil and plant samples as soon as any abnormal plant symptoms are observed and have them tested.

If plant analysis and/or soil testing show a need for additional nutrients, use materials shown in Table 1. In most cases, 0.5 lb per 100 yd^2 of the nutrient element in need will correct the problem. For example, if nitrogen is low, a top dressing of 3–5 lb nitrate of soda (16-0-0) per 100 yd^2 will be sufficient.

Micronutrients (Mn, Cu and Zn)

Micronutrient needs for plant beds should be determined by a soil test prior to plant bed preparation. Generally, micronutrients do not present a problem in tobacco plant beds. However, if they test low, a *$* symbol will appear in the *Recommendations* section for the micronutrient in question. The *$ Note* included with your soil test report will offer suggestions on application rates. If plant growth problems occur and micronutrients are suspected, collect a plant tissue sample along with a soil sample and send them to the Agronomic Division for testing.

NOTE 3: Fertilization of Field Crops (revised November 2007)

Lime Sources

Liming is the application of calcium or calcium-magnesium compounds that are capable of neutralizing soil acidity (raising the soil pH). Two major types of lime are used for agricultural purposes: calcitic and dolomitic. Calcitic limestone is composed of calcium carbonate ($CaCO_3$) and contains little or no magnesium. Dolomitic limestone is a mixture of calcium and magnesium carbonates [$CaMg(CO_3)_2$] and contains, by state law, 6 percent or more magnesium. Most lime sold in North Carolina is dolomitic lime. Agricultural grade lime, or ag lime, must meet specifications in fineness of grind and guarantee a neutralizing value established by state law.

Lime Rates

The rate (tons per acre) of lime recommended on the soil test report should raise the pH to

- 5.0 for organic (ORG) soils,
- 5.5 for mineral organic (M-O) soils and
- 6.0 to 6.2 for mineral (MIN) soils, depending on the crop to be grown.

The recommended rate varies depending on the level of soil acidity and the target pH for each soil type. The pH obtained with a given rate of lime varies depending on uniformity of application, particle size, neutralizing value, method and depth of incorporation, and soil texture.

When lime is recommended, apply it as early as possible to allow enough time to neutralize soil acidity. For best results, use a high-quality ag lime and incorporate it thoroughly into the top 8 inches of soil. Apply and incorporate lime prior to beginning reduced or no-till systems if possible. Maintenance applications can be surface applied.

A low soil pH is associated with low levels of calcium and/or magnesium as well as high soil acidity. As the level of soil acidity increases, aluminum increases and becomes toxic to plants. The efficiency of nutrient uptake and use decreases as well.

A high soil pH can reduce manganese availability. Manganese deficiencies may occur on sandy coastal plain soils when lime is applied in excess of the recommended rates. Therefore, follow soil test recommendations as closely as possible.

Magnesium leaches readily from sandy coastal plain soils. When a soil test report recommends lime and magnesium levels are low, dolomitic lime is the most economical source of both. When a soil is low in magnesium, the soil test report will have a *$* symbol in the *Mg* column of the *Recommendations* section. If there is a *$* symbol but no lime is recommended or calcitic lime has already been applied, then add 20–30 lb Mg per acre from a readily soluble source to your fertilizer until a subsequent soil test shows an adequate level.

Corn

The rate of N, P_2O_5 and K_2O recommended on the soil test report should produce high yields as long as other factors that influence yield are optimized. These include lime needs, planting date, population, soil moisture and nitrogen management.

Nitrogen has more influence on corn yield than any other fertilizer input. Extreme variation in soil and climatic conditions across North Carolina make managing the timing and rate of application difficult. The rate recommended on the soil report (120–160 lb N per acre) can be adjusted depending on soil type and expected yield potential. See section **Realistic Yield Expectation (RYE) N Rates** for more information.

For irrigated corn, you may need to increase nitrogen rates 10 to 15 percent, particularly if the plant population is increased. This is especially true on sandy coastal plain soils where nitrogen is more subject to leaching.

Under most soil and climatic conditions, all the recommended P_2O_5 and K_2O can be broadcast before planting. However, banded starter fertilizers, such as 10-34-0 or 18-46-0, have been shown to stimulate rapid early growth and/or promote uniformity in cool, wet soils. By stimulating rapid early growth, starter fertilizers reduce the potential of billbug damage and often hasten maturity.

In general, starter fertilizers should be banded at the rate of 20–40 lb of N and P_2O_5 per acre, two inches to the side and two inches below the seed at planting. The P_2O_5 applied as a starter should be subtracted from the total P_2O_5 recommended. The total N and K_2O applied in a band should not exceed 70–80 lb per acre to avoid salt injury to seedling plants.

Sulfur deficiency may occur on sandy coastal plain soils following periods of excessive rain or heavy irrigation, especially when the subsoil is deeper than 16 inches. Although less likely, levels of plant-available sulfur can also be limiting in organic soils.

The soil test report gives a sulfur recommendation whenever S-I < 25. Since sulfur leaches as readily as nitrogen, it may be adequate at the time of the report but be limiting later during the season. Plant tissue analysis can be used in-season to test for sufficiency.

Soybeans

On most soils, the P_2O_5 and K_2O recommended on the soil test report can be applied before planting.

Manganese deficiency on soybeans is commonly observed on sandy coastal plain soils when the pH exceeds 6.2. Therefore, never apply more lime than recommended on the soil test report. If a Mn deficiency occurs due to overliming, the *$ Note* that accompanies the report offers advice on dealing with this problem.

Manganese deficiency is also prevalent on some sandy coastal plain soils due to the inherently low Mn levels in these soils. When low Mn is confirmed by a soil test, broadcast 10 lb of water-soluble Mn per acre before lime is applied. This rate should supply the Mn requirement of plants for several years.

Soybeans heavily infested with cyst nematodes may show symptoms much like manganese deficiency. Consequently, fields with a history of cyst nematodes should be analyzed for nematodes as well as for soil and plant tissue nutrient levels.

Double Crop: Small Grain/Soybeans

Apply only the recommended rates of lime to avoid raising the soil pH too much. Manganese deficiency is common when the pH is 6.2 or higher, particularly on sandy coastal plain soils. This deficiency has adverse effects on yields of small grains and/or soybeans. If a deficiency occurs, follow the advice in the *$ Note*, which should arrive in the mail with your soil test report.

For small grains grown on sandy coastal plain soils where nitrogen is subject to leaching, apply 20–30 lb N per acre at planting with the remainder top-dressed in late February or early March. On heavy-textured soils of the piedmont and mountain regions, apply one-third at planting and top-dress with the remainder in late February or early March. See section **Realistic Yield Expectation (RYE) N Rates** for more information.

Apply the recommended P_2O_5 and K_2O prior to planting. In most cases, the P_2O_5 and K_2O recommended for double-cropped soybeans can be applied to the preceding small grain crop. The feasibility of this practice depends upon the capacity of individual soils to hold phosphorus and potassium against leaching.

Phosphorus leaches from soils high in organic matter with little or no mineral component. Therefore on these soils, apply any recommended P_2O_5 directly to the soybean crop.

Potassium leaches from sandy coastal plain soils with a low cation exchange capacity. On these soils, apply recommended K_2O directly to the soybeans.

On soils that have the capacity to hold phosphorus and potassium, the rate of P_2O_5 and K_2O recommended for soybeans following small grain can be reduced by one-half and applied with the P_2O_5 and K_2O recommended for the small grain crop.

Sulfur deficiency may occur on small grains, especially on deep sandy soils after leaching rainfall. Deficiency is particularly likely when the subsoil is deeper than 16 inches and when no sulfur has been applied to the previous crop.

The soil test report gives a sulfur recommendation whenever S-I < 25. Since sulfur leaches readily, it may be adequate at the time of the report but be limiting later during the season. To monitor sulfur levels during the growing season, take plant tissue samples and send them to the NCDA&CS lab for analysis.

Double Crop: Small Grain/Grain Sorghum

Use the nitrogen recommendations on the soil test report as a guide. Fertilize with P_2O_5 and K_2O as described for soybeans double-cropped behind small grain.

Peanuts

Lime is essential for successful peanut production. It is a major source of calcium and magnesium, boosts the efficiency of nutrient uptake and use, promotes nodulation and nitrogen fixation and reduces the potential of aluminum toxicity. The pH range for optimum peanut production is from 5.8 to 6.2.

Landplaster (gypsum) is often used as a source of calcium. When applied to extremely acid soils (pH < 5.0), it can raise aluminum levels within the root zone, resulting in poor growth and reduced yields and quality. This problem can be prevented by using lime instead of landplaster.

Large-seeded, Virginia-type peanuts require a high calcium content in the soil surface at pegging for pod development and production of quality peanuts. Landplaster applied in late June to mid-July in either of the following ways meets this requirement:

- 600–800 lb per acre of finely ground gypsum applied in a 16- to 18-inch band over the row at first bloom;
- 1200–1500 lb per acre of granular gypsum or 1800–2000 lb per acre of by-product gypsum broadcast.

The acidity associated with by-product gypsum requires that soil pH be monitored more frequently.

Excessive potassium can be detrimental to a peanut crop. High levels within the fruiting zone (top 2–3 inches of soil) are associated with pod rot. Potassium also competes with calcium uptake at pegging, resulting in a high percentage of "pops." Therefore, apply any potash (K_2O) recommended for the peanut crop along with the preceding crop's fertilizer. If this cannot be done, apply and incorporate the recommended K_2O as far before planting as possible to allow enough time for potassium to move below the fruiting zone before pegging.

Apply any recommended P_2O_5 in one of two ways: along with fertilizer for the preceding crop; or directly to the peanut field prior to planting.

Manganese deficiency may occur when the soil pH exceeds 6.2. If you suspect a manganese deficiency, collect soil and plant samples and have them analyzed. The *$ Note* that accompanies the soil test report gives advice on this problem.

Peanuts are extremely sensitive to zinc. Toxicity, and sometimes plant death, may occur when the zinc-availability index (Zn-AI) is 250 or greater. Establishing a pH of 6.0 or higher minimizes risk of zinc toxicity. See the *$ Note* (mailed with your report) for details.

The amount of boron recommended on a soil test report (0.5 lb B per acre) prevents hollow heart in peanuts. Boron can be applied as a preplant broadcast treatment along with other fertilizer applications, or with the preplant incorporated herbicide application. Alternatively, apply 0.25 lb B per acre as a foliar spray near blooming prior to fruiting. Apply another 0.25 lb two weeks later. The total rate of boron should not exceed 0.5 lb per acre.

Cotton

A soil pH near 6.2 is essential for the production of high-yielding, quality cotton. Cotton is very sensitive to soil acidity and has a high calcium requirement for quality lint production. Liming neutralizes soil acidity, supplies the calcium and magnesium required for plant growth and fiber production, and promotes the efficient use of other plant nutrients.

Rate and timing of nitrogen applications strongly influence cotton yield. Low nitrogen reduces yield. Too much nitrogen causes excessive vegetative growth, makes pesticide coverage more difficult, delays fruiting and maturity, increases attractiveness to insects and reduces the effectiveness of defoliants.

The nitrogen rate (50–70 lb per acre) given on the soil test report can be adjusted depending on soil type and expected yield potential. See section **Realistic Yield Expectation (RYE) N Rates**.

On sandy coastal plain soils where nitrogen is subject to leaching, apply 20–25 lb per acre at planting with the remainder side-dressed shortly after formation of squares. On deeper sandy soils where leaching is extensive, apply side-dressed nitrogen in split applications. Apply all nitrogen by mid-June.

In most cases, apply all recommended P_2O_5 and K_2O at planting. High-phosphate starter fertilizer (10-34-0), banded at planting, can enhance growth and maturity for cotton planted early on cool soils. Place banded starter fertilizer 2 inches to the side and 2 inches below the seed to avoid salt injury to young seedlings. On deep, sandy-textured soils where potassium leaches, consider split applications of K_2O.

Boron is essential for good bloom set, seed development, and fiber production. The boron recommended on a soil test report (1.0 lb per acre) is for broadcast application during seedbed preparation. Alternatively, if borated fertilizer is banded, apply 0.2–0.4 lb actual B per acre. For foliar application, use 0.25 lb B per acre at early bloom followed by another 0.25 lb after two weeks. Select a highly water-soluble boron source. Monitor the boron status during the season with plant tissue analysis.

Sulfur deficiency can occur on sandy coastal plain soils where the clay is below 16 inches, particularly in seasons of excessive rainfall. Rates of 20–25 lb per acre applied along with the fertilizer safeguard against sulfur deficiency under most soil and climatic conditions. Since sulfur and nitrogen deficiencies are similar, submit plant tissue and soil samples for problem analysis and verification.

The soil test report gives a sulfur recommendation whenever S-I < 25. Since sulfur leaches readily, it may be adequate at the time of the report but be limiting later during the season. To monitor sulfur levels during the growing season, take plant tissue samples and send them to the NCDA&CS lab for analysis.

Realistic Yield Expecation (RYE) N Rates

More specific nitrogen rates can be used based on realistic yield expectations by soil type. These rates are required for waste and nutrient management plans in some N.C. river basins. Rates using the RYE approach are available online at www.soil.ncsu.edu/nmp/yields/.

Livestock and Poultry Manures

Farm manures can be valuable sources of N, P_2O_5, K_2O (Table 1) and, in some cases, the micronutrients zinc and copper. Since nutrient content varies with rate and method of application, it is best to have the manures analyzed for nutrient content near the time of application. NCDA&CS offers a basic waste analysis for a fee of $5.00 per sample and special tests (lime equivalence, heavy metals, nitrogen breakout) for an additional fee of $10 per test per sample.

Repeated applications of animal waste can lead to high levels of zinc and copper within crops. Excessive levels can be toxic to plants and cause reproduction problems in livestock. Test soils regularly to determine when to discontinue application of manures for a particular site.

Table 1. Average plant nutrients available the first year after broadcast application of animal waste. *

	N	P_2O_5	K_2O
		lb/ton	
Broiler house litter (>6,000 samples)	29.0	26.8	40.0
Turkey house litter (>2,500 samples)	24.2	28.0	26.6
		lb/1000 gallons	
Anaerobic swine lagoon (>38,000 samples)	1.8	1.0	5.4
Dairy manure slurry (>1,500 samples)	4.6	4.2	9.7

* Based on NCDA&CS waste analyses, 1999 to 2006.

NOTE 4: Fertilization of Lawns, Gardens and Ornamentals
(revised April 2007)

Lime

Lime is a primary ingredient for improving the soil environment and promoting plant growth. Lime neutralizes soil acidity, improves soil tilth, stimulates microbial activity, enhances the availability of key nutrient elements and supplies the essential nutrients calcium and magnesium. No other amendment contributes so many benefits to the soil environment.

There are two types of lime used for agricultural purposes: calcitic and dolomitic. Calcitic limestone contains calcium carbonate ($CaCO_3$) but little or no magnesium. Dolomitic limestone contains both calcium and magnesium carbonates [$CaMg(CO_3)_2$] and has at least 120 lb Mg per ton.

Most bagged lime sold by farm suppliers and garden centers is a finely ground, high quality agricultural grade of dolomitic lime. Pelletized lime used as specified on the label should be equally as effective.

Lime recommendations on the soil test report are expressed in units of M, which is the same as lb/1000 ft^2. The rate suggested should raise the pH to 5.5 for centipedegrass, 6.0 for other lawn grasses and 6.0 to 6.5 for gardens. The lime application should keep soil pH within the desired range for two to three years on sandy coastal plain soils and for three to four years on silt and/or clay piedmont and mountain soils.

For gardens and newly established lawns, broadcast lime over the surface and incorporate it 4–8 inches into the soil. For established lawns, gardens and ornamental shrubs, apply the recommended lime over the surface prior to rainfall or irrigation.

Do not surface-apply more than 50 lb of lime per 1000 ft^2 at any given time. If the suggested rate is higher, apply 50 lb initially and the remainder six months later. Lime residue will not harm plants and can be removed easily by irrigation or rainfall.

Apply lime based on a current soil test. Overliming can reduce the availability of certain micronutrients. This problem is common on sandy coastal plain soils.

Fertilizer

The numbers on the fertilizer bag represent the grade of fertilizer: that is, the percentage of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) contained in the material. All fertilizer grades are identified by the same label sequence (%N-%P_2O_5-%K_2O). For example, 20 lb of 10-10-10 contain 2 lb of N, 2 lb of P_2O_5 and 2 lb of K_2O.

If you have a bag of 10-10-10 and want to apply 1 lb of nitrogen per 1000 ft^2, you would calculate the amount to apply as follows:

$$\frac{\textit{lb N desired} \,/\, \textbf{1000 ft}^2}{\textit{\%N found in 10-10-10}} = \frac{\mathbf{1.0}}{\mathbf{0.10}} = \mathbf{10\ lb/1000\ ft^2}$$

The number of pounds of the nutrient you want to apply per unit area divided by the grade percentage gives the amount of fertilizer to apply. Therefore, 10 lb of 10-10-10 supply 1.0 lb of N.

Use the same method for calculating the rate requirement from any fertilizer grade. The desired nutrients can also be obtained from single-nutrient fertilizers such as ammonium nitrate (34-0-0, 34% N) for N, muriate of potash (0-0-60, 60% K_2O) for K, and triple superphosphate (0-46-0, 46% P_2O_5) for P.

The rate of fertilizer recommended on the soil test report is in units of M, which is the same as lb/1000 ft^2. Read on for crop-specific information.

For lawns in general. The fertilizer rate given on the soil test report supplies enough phosphorus and potassium for an entire season. However, applying K_2O at a rate of 1.0 lb/1000 ft^2 in the fall improves the winter hardiness of warm-season grasses.

Table 1 gives the nitrogen fertilization schedules for common lawn grasses. The fertilizer rates on the soil test report supply 1.0 lb N per 1000 ft^2 for all lawn grasses, except centipedegrass. Subtract the nitrogen rates suggested on the soil test report from the total nitrogen shown in the table. Rates greater than those shown in the table enhance disease pressure, drought stress and winter injury.

Table 1. Nitrogen fertilization (lb/1000 ft^2)

For cool-season grasses*

	Feb	Sept	Nov
tall fescue	1	1	1
tall fescue & Kentucky bluegrass	1	1	1
fine fescue & Kentucky bluegrass	1	1	1
perennial ryegrass & Kentucky bluegrass	1	1	1–2
Kentucky bluegrass	1	1	1–2

For warm-season grasses*

	May	June	July	Aug
common bermuda	1	1	1	1
hybrid bermuda	1–1.5	1–1.5	1	1
centipede	–	0.5	–	–
St. Augustine	1	0.5	1	0.5
zoysia	1	0.5	–	0.5
bahia	1	–	0.5	–

* The fertilizer recommended on the soil test report will supply the annual P_2O_5 and K_2O requirements. Choose a fertilizer that will not exceed the nitrogen rate recommended for specific applicaiton periods. This table gives additional nitrogen requirements and specified times of application.

For centipedegrass lawns. The recommended nitrogen fertilization rate for centipedegrass is only 0.5 lb/1000 ft^2. Nitrogen rates that are suitable for other lawn grasses cause excessive growth and winter injury on centipedegrass.

If you have a centipedegrass lawn and did not specify this when submitting your soil sample, your lime recommendation probably is in error. If this is the case, check the soil pH on your soil test report. If it is 5.5 or higher, do not apply any lime. If it is below 5.0, apply 50 percent of the lime recommended on the report.

Table 2. Supplemental nitrogen for vegetables

Crop	Rate (lb/1000 ft^2)	Schedule
tomatoes	0.5–1	2 applications at monthly intervals > 1st bloom
potatoes	1.5–2	1 month > emergence
sweet corn	1.5–2	1 month > emergence
cabbage	0.5–1	1 month > transplanting
squash	0.5–1	1 month after emergence
okra	0.5–1	when plants are 2 ft high
beans	0.5–1	1 month > emergence
peppers	0.5–1	1 month > transplanting

Centipedegrass is sensitive to overliming. It turns yellow due to an iron deficiency when soil pH is high. Consequently, if the pH is above 5.9, acidify the soil as described under the heading **For azalea, camellia, mountain laurel and rhododendron**.

If centipedegrass yellows due to an iron deficiency, a foliar application of iron will solve the problem temporarily. However, a nematode infestation can also cause similar symptoms. Therefore, if yellowing occurs, submit separate soil samples for nematode assay and soil fertility.

For vegetable and flower gardens. Spread the recommended amount of fertilizer uniformly over your garden plot. Incorporate it 4–6 inches into the soil before seeding or transplanting. This method of application reduces the potential of salt injury to germinating seeds or young transplants.

Alternatively, broadcast about 3/4 of the fertilizer over the surface and incorporate it. Band the remainder in the row: 2–3 inches to the side and 2 inches below the seed at or prior to planting. Keep in mind that fertilizers are salts. Applying too much can have adverse effects on seed germination or on young transplants.

Certain vegetable crops require additional nitrogen during the growing season. Side-dress the extra nitrogen at the rates and times specified in Table 2. Irrigate following application to enhance movement of nutrients into the root zone.

For azalea, camellia, mountain laurel and rhododendron. These plants have similar requirements. They are acid-loving plants and grow best when the soil pH ranges from 4.8 to 5.5. Azalea and camellia fertilizers are generally acid-forming, which is an added benefit if the soil pH is too high (above 6.0).

Recommendations on the soil test report supply 1 lb N per 1000 ft^2, a rate sufficient for one year's growth. However, splitting fertilizer treatments into three equal applications will produce more uniform growth and minimize leaching: 1/3 in early April, 1/3 in June or July and 1/3 in September.

Many factors cause leaf yellowing on these shrubs: iron deficiency due to high soil pH, use of new or undecomposed organic matter, poor internal drainage, excessive fertilizer application, root diseases, nematodes and/or insects. Consequently, before taking any corrective action, collect soil and plant tissue samples and have them analyzed.

If test results indicate an iron deficiency, apply a water-soluble iron fertilizer to the leaves, using the rates on the label. Reapply if symptoms reappear.

If the soil pH is above 6.0, apply 3–4 lb elemental sulfur or 20–30 lb iron sulfate per 1000 ft^2. Irrigate the treated area thoroughly to enhance reaction and remove any residue on the plants. Higher rates could damage plant roots by lowering soil pH too rapidly. Take a soil sample two to three months after any acidification process to determine if further adjustment is required.

For roses. Roses have a high calcium requirement. Lime recommendations are designed to maintain soil pH within a range of 6.0 to 6.5. A rate of 50 lb/1000 ft^2 is equivalent to spreading 1/2 cup around a plant to a distance of 18 inches. For best results, mix lime into the top 3–4 inches of soil.

Apply the recommended fertilizer in April or when the first flower buds appear. Apply additional nitrogen at rates of 0.5–1.0 lb/1000 ft^2 at monthly intervals through August. Water thoroughly following fertilizer application. Apply specially formulated fertilizers as indicated on the label.

For other ornamental shrubs. The fertilizer recommendation on the soil test report provides enough plant nutrients for one year. The best time to apply fertilizer is in the early spring, usually one month prior to the most rapid growth period.

For individually transplanted shrubs, incorporate 0.25–0.5 lb of lime into the soil removed from the transplant hole before replacing it around the plant. Spread fertilizers evenly around the plant 10–12 inches from the base and water thoroughly.

In cases where many plants are being planted in beds, incorporate lime and fertilizer prior to setting plants. Ideally, you should incorporate any recommended lime several weeks before planting to allow adequate time to neutralize soil acidity.

For shade trees. The fertilizer rate given on the soil test report provides the nutrients required for the entire growing season. Apply fertilizer in February or March, prior to budding. Mature trees growing within a lawn seldom need any fertilizer beyond that applied to the lawn.

To fertilize individual trees, convert the rate from lb/1000 ft^2 to lb/inch of tree diameter. Multiply lb/1000 ft^2 by 0.05 when the tree is less than 6 inches and by 0.1 when the trunk is greater than 6 inches in diameter. Spread the fertilizer evenly around the tree starting 12 inches from the trunk and extending just beyond the drip line.

NOTE 5: Fertilization of Christmas Trees (revised February 2008)

High quality Christmas tree production (blue spruce, cedar, Fraser fir, hemlock, Leyland cypress, Norway spruce, Virginia and white pines) requires a properly adjusted pH and an adequate supply of all essential nutrients. Soil fertility promotes maximum tree growth as well as desired dark green color and retention of needles. Trees derive the most benefit from lime and fertilizer when applied at the appropriate time with correct placement.

Soil pH and Lime

Soil pH affects the availability of essential plant nutrients as well as potentially acidic elements (aluminum, hydrogen, manganese) that can be toxic to plant roots. Lime raises soil pH by neutralizing acidity while supplying calcium (Ca) and/or magnesium (Mg).

Lime is either calcitic (calcium carbonate) or dolomitic (calcium magnesium carbonate). In North Carolina, most commercially available lime is dolomitic. Choose dolomitic lime when soil Mg levels are low, as indicated by a dollar symbol (*$*) in the Mg column of the Recommendations section of the soil test report.

Table 1. Target soil pH

white pine, Virginia pine	pH 5.5
Fraser fir, hemlock, Norway spruce	pH 5.8, establishment pH 5.5, maintenance
Leyland cypress	pH 6.0
blue spruce, red cedar	pH 6.5

All materials sold as lime in North Carolina are regulated under the N.C. Lime Law. This law requires that a ton (2000 lb) of dolomitic lime contain at least 6% (120 lb) soluble Mg.

The soil test report lime recommendation is given in tons/acre (T) to raise the pH to the desired target (Table 1). Lime reacts faster and reduces soil acidity more effectively if mixed into the soil to a depth of six to eight inches. Typically, this can only be done before establishing a new planting.

Soil pH management is more difficult in established fields. Surface applications react slowly due to limited soil contact and lime's low water solubility. As a result, samples analyzed 12–18 months after a surface application, especially under prolonged drought periods, may still indicate low pH in the root zone and a need for additional lime. In established fields, a 4-inch sample depth more accurately predicts lime needs.

If too much lime is applied, soil pH can become too high and adversely affect the availability of nutrients, especially micronutrients. When surface-applying lime, never apply more than 1.5 T at any given time. Wait 12 months before applying any additional lime.

Calcium (Ca)

Calcium promotes adequate shoot and root development. It also reduces needle drop. Christmas trees have a high Ca requirement and may need more Ca than lime supplies. When that is the case, use calcium sulfate ($CaSO_4$), commonly called gypsum. This relatively soluble fertilizer contains 20–22% calcium and 18% sulfur. It will not increase soil pH.

A Ca% level of 50–55 is sufficient for Christmas tree production, depending on the soil's cation exchange capacity (CEC), as found on the soil test report. For example, values of Ca%=50 and CEC=5 indicate 891 lb/acre of available Ca. A soil with Ca%=50 and CEC=10 contains 1792 lb/acre of available Ca.

The Ca% and CEC values given on the soil test report help determine the rate of gypsum (lb/acre) to apply. The rate in Table 2 assumes a 22% Ca content for gypsum. To convert lb/acre to lb/tree, divide by 1742 (based on 5×5-ft tree spacing). Spreading gypsum in a 12-inch band outward from the drip line of trees increases the efficiency of Ca uptake.

If the soil test report recommends lime and Ca% < 45, you need to apply both recommended lime and gypsum at a rate of 10–12 ounces per tree. On these sites, a Ca% value of 45 is sufficient if lime is not recommended.

Magnesium (Mg)

Magnesium is necessary for good tree color. On your soil test report, look for a symbol in the Mg column of the Recommendations section: *0* indicates that Mg levels are sufficient; *$* indicates that levels are low. Refer to the *$ Note* included with your soil test report for additional information on Mg.

Table 2. Gypsum application rates (lb/acre)

	Ca% value given on soil test report									
CEC	45	46	47	48	49	50	51	52	53	54
2.0	325	290	260	225	195	160	130	100	65	30
4.0	650	580	520	455	390	325	260	200	130	65
4.5	730	655	580	510	435	365	290	220	145	75
5.0	810	730	650	565	485	405	325	245	160	80
5.5	890	800	715	625	535	445	355	265	180	90
6.0	975	875	780	680	585	485	390	290	191	100
6.5	1055	850	840	735	630	525	420	315	210	105
7.0	1135	1025	910	795	680	570	455	340	225	115
7.5	1215	1095	970	850	730	610	485	365	245	120
8.0	1300	1170	1035	910	780	650	520	390	260	130

Table 3. Magnesium application rates *

Source	**lb/acre**	**lb/1000 ft²**
Magnesium sulfate[10% Mg, 13% S]	200	4.6
Sulfate of potash [11% Mg, 22% K_2O, 22% S]	182	4.2
Magnesium oxysulfate [36% Mg, 6% S]	56	1.3

* Rates supply 20 lb per acre of magnesium.

Dolomitic lime is an excellent source of Mg, but do not apply it unless the soil test report indicates that lime is needed. If Mg is needed (*$*) but lime is not, apply 20–25 lb/acre of a water-soluble source. Sulfate of potash magnesia (0-0-22, 11% Mg, 23% sulfur) is a good source of Mg. If the soil test Mg% value > 20, use calcitic lime. Adding additional Mg when levels are already in excess of 20 percent could contribute to Ca and/or K deficiency.

Table 3 lists sources of this nutrient and rates that will provide 20 lb/acre of Mg. Blending these materials with other fertilizers ensures a more uniform application.

High Soil pH Concerns & Management

If needles turn yellow or show other nutrient deficiency symptoms, soil pH may be too high. High pH can limit availability of many micronutrients, especially manganese. Before taking corrective action, collect both soil and plant tissue samples and have them analyzed.

If the soil test confirms abnormally high pH, apply either elemental sulfur (S) (flowers of sulfur, 90% S) or ammonium sulfate (21-0-0). For sandy textured soils with low CEC values and a pH of 6.0–6.2, apply enough ammonium sulfate to meet the annual nitrogen requirement.

On heavy-textured soils (high in organic matter or clay) with high CEC values and pH > 6.2, apply elemental sulfur at a rate of 150–200 lb/acre or 1.4–1.8 oz/tree.

Spread S around trees in a 12-inch swath from the drip line outward. Even distribution helps prevent development of zones of extremely acid soil.

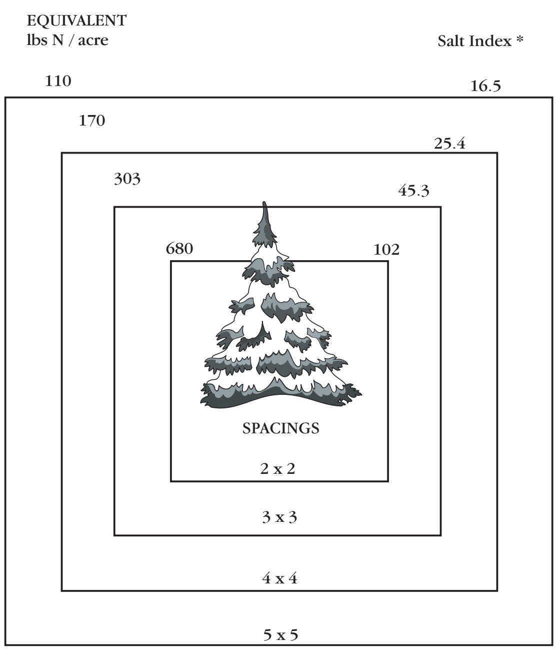


Figure 1. Nitrogen rate and salt index based on area of application of ammonium nitrate

Table 4. Nitrogen application rates for seed/lineout beds

Source	lb/400 ft²
Ammonium nitrate [33% N]	3
Calcium nitrate [15.5% N]	6.5
Ammonium sulfate [20.5% N]	5
Urea [46% N]	2
Diammonium phosphate [18% N, 46% P_2O_5]	5

Table 5. Field nitrogen rates

Age of tree in field	N rate (oz/tree) Spring	Fall
1 to 2 years (establishment)	0.5	–
3 years and older (maintenance)	0.5	0.3–0.5

Higher rates of S can be incorporated into lineout beds prior to planting. However, do not exceed 300–350 lb per acre or 7–8 lb per 1000 ft². Irrigating after a S application enhances its rate of reaction.

Phosphate (P_2O_5) and Potash (K_2O)

The rates of P_2O_5 and K_2O recommended on the soil test report are in units of lb per acre for field production and lb per 1000 ft² (abbreviated M) for nursery or lineout beds. Relatively high levels of soil phosphorus (P) promote tree development and good bud set. Rapid growth during the third year of production increases need for potassium (K).

Try to apply P uniformly and incorporate it into the soil whenever possible. In acid soils, P is converted to forms that are unavailable for plant uptake. Liming counteracts this process and increases the amount of P available to plants. Therefore, apply any recommended lime before fertilizing with P. If this is not possible, you can apply lime and P simultaneously.

Unlike P, K moves into the soil even if it is not incorporated. If the soil test report recommends applying more than 100 lb/acre of K_2O, apply half in the spring and half in the fall. Applying more than 50 lb/acre at one time increases the risk of soluble salt injury, especially during dry weather. Salt injury is more likely with potassium chloride (0-0-60) than with potassium sulfate (0-0-50).

Applying gypsum at this time may reduce K levels in the root zone. Monitor K status with soil and plant analysis at least every two years to ensure sufficiency.

Nitrogen (N)

Proper N application optimizes efficiency of nutrient uptake, promotes maximum growth and reduces chance of soluble salt injury. Recommended rates are based on uniform application to a 5×5-ft area. If the same amount (e.g., 1.0 oz of nitrogen) is applied over a smaller area, both the rate of application and the soluble salt index increase in direct proportion to the reduction in area (Figure 1).

—Seed/Lineout Beds. Apply N at a rate of 1.0 lb per 400 ft² (~2.5 lb per 1000 ft²) as a single treatment in the spring prior to bud break. See Table 4 for comparable rates of specific N fertilizers. Apply when foliage is dry and follow with 0.25 inch of irrigation to prevent leaf burn.

—Field Establishment. Apply N one month after transplanting or two weeks before bud break on fall- or winter-planted trees. You may want to reduce the fertilizer rate for trees less than three years old. For example, if you apply N over a 3x3-ft area (9 ft²) instead of a 5x5-ft area (25 ft²), apply one-third of the total N recommended. Spread N in a 12-inch band from the drip line outward. On small trees, apply N 12 inches from the base of the trunk.

—Field Maintenance. The rate of N recommended on the soil test report (90–110 lb/acre) is the total annual requirement for broadcast field application. This rate delivers approximately 1.0 oz N per tree based on a 5x5-ft tree spacing. Table 5 shows a schedule for applying N based on age of tree in the field.

NOTE 6: Fertilization of Commercial Vegetable Crops

(January 2007)

Successful commercial vegetable production depends on the management of many different components, with soil fertility being one of the primary considerations. Following soil test recommendations for lime and fertilizer should produce optimum yields under average climatic conditions as long as other aspects of standard good management are practiced.

Soil testing helps ensure a good economic return for each dollar spent on fertilizer. Following soil test recommendations also helps protect the environment from pollution by excess fertilizer nutrients. This note provides guidance for making soil fertility decisions related to field production of vegetables where plasticulture is not used.

Lime

The NCDA&CS recommends having soil tested every two to three years to determine lime and fertilizer needs. Liming to the target pH for the crop you intend to grow creates favorable conditions for rooting by neutralizing soil acidity and supplying calcium and/or magnesium. Most vegetable crops grow best at a target pH of 6.0, but 6.5 is recommended for tomatoes and for establishment of asparagus.

Two types of lime are commonly available in N.C.: calcium carbonate (calcitic lime) and calcium magnesium carbonate (dolomitic lime). On coarse-textured (sandy) soils where leaching is a concern or

Table 1. N recommendations (lb per acre) for selected vegetable crops

Crop	Total N Rate	Application Method & Timing	N per Application
Bell pepper	80–130	planting, broadcast	40–50
		1st fruit set, sidedress	40–50
		later in season, if needed	40–50
Cabbage	100–150	planting, broadcast	50–75
		2–3 wks postplant, sidedress	25–50
		late in season, if needed	25–50
Cucumber (field)	80–140	planting, broadcast	40–80
		2 wks postplant	20
		1st vine run	20–40
Irish potato	100–150	planting, broadcast	50
		4–5 wks postplant, sidedress	50–100
Sweetpotato	60–90	planting	0
		3–4 wks postplant	60–90
Tomato (field)	90–120	planting, broadcast	45–60
		1st fruit set, sidedress	45–60

on soils with low levels of magnesium, it is best to use dolomitic lime. Agricultural grade limestone provides maximum reactivity and effectiveness, especially when incorporated into the soil 6 to 8 inches deep in conventional tillage situations.

Nitrogen (N), Sulfur (S) & Potash (K_2O)

Recommended total nitrogen rates depend on the crop (Table 1) and, to some extent, on soil productivity. The timing of the application is very important for efficient use. Good nitrogen sources include calcium nitrate (15.5-0-0), diammonium phosphate (18-46-0), ammonium sulfate (21-0-0) and various nitrogen solutions.

Note: Sodium nitrate (16-0-0) and ammonium nitrate (34-0-0) are also excellent sources, but they will be unavailable soon.

Sulfur helps a plant use nitrogen efficiently so it is not surprising that deficiency symptoms for nitrogen and sulfur (yellow leaves) are similar and often confused. Sulfur deficiency tends to occur on coarse-textured (sandy) soils. Rainfall washes sulfur out of the root zone and into the subsoil, especially on deep sands. Although less likely, levels of plant-available sulfur can also be limiting in organic soils.

The soil test report gives a sulfur recommendation whenever S-I < 25. Since sulfur leaches as readily as nitrogen, it may be adequate at the time of the report but be limiting later during the season. Plant tissue analysis can be used in-season to test for sufficiency. Fertilizers that supply sulfur include ammonium sulfate (21-0-0-24), potassium sulfate (0-0-50-18) and sulfate of potash-magnesia (0-0-22-22).

Potash may also be a concern on sandy soils. If tomatoes and peppers are growing on sandy soils where leaching has occurred, it may be beneficial to apply similar amounts of potash and nitrogen at sidedress. If you suspect leaching of nutrients from coarse-textured (sandy) soils, you can use plant tissue tests to find out if supplemental applications of nitrogen, potassium and sulfur are needed.

Boron (B)

Boron is an essential nutrient that plants need in minute quantities. High soil levels can be toxic to plants. Boron is less available to plants when the soil pH is above 6.5; it also tends to leach from sandy soils.

NCDA&CS soil tests do not measure boron, but reports do recommend annual application for certain vegetable crops that are especially sensitive to boron deficiency. These crops include broccoli, brussel sprouts, cabbage, cantaloupe, cauliflower, collards, field cucumbers, okra, peppers, radish, rutabaga, tomato, turnip, and watermelon. In production of asparagus, boron should be applied to the soil every third year.

NCDA&CS recommends a broadcast application of 1 to 2 lb/acre at planting. The lower rate is recommended on coarse-textured (sandy) soils to reduce the risk of toxicity.

Boron can be put out as a foliar application, but timing is very critical to achieve desired results. The recommended rate is 0.2 lb/acre boron in sufficient water for coverage. Apply foliar boron as follows: prior to heading of cole crops, prior to root swell in root crops, and at first bloom for tomatoes and okra.

Special Concerns —Manganese (Mn) Deficiency

Levels of this essential micronutrient are often low in mineral soils of the coastal plain. Because manganese becomes more unavailable as the soil pH increases above 6.3, excessive liming should be avoided.

Snap beans, vine crops and tomatoes, in particular, benefit from adequate levels of manganese. If soil test levels are low, broadcast manganese at a rate of 10 lb/acre. If manganese is unavailable due to high soil pH, apply 0.5 lb/acre as a foliar spray. Try two applications about 10 days apart when deficiencies are severe.

—Blossom End Rot

Calcium (Ca) deficiency causes this common tomato problem—a rot on the bottom of the fruit (blossom end). The problem can occur in dry weather even if calcium levels in the soil are adequate because plant uptake is limited.

To supply calcium to the soil, use calcium nitrate (a good nitrogen source) or calcium sulfate (also know as gypsum or landplaster). To apply calcium directly to the fruit, spray 4 lb of calcium nitrate or calcium chloride per 100 gallons of water (4 tbsp/gallon water) every 7 to 10 days for at least two to three applications.

—Magnesium (Mg) Deficiency

Often seen on tomato, symptoms include interveinal chlorosis of the lower leaves. The problem frequently occurs on sandy soils, where magnesium reserves are limited due to low cation exchange capacity (CEC). Magnesium also tends to leach from these soils.

If lime is needed, dolomitic lime is a good source of magnesium. If lime is not needed and soil magnesium levels are inadequate, apply enough sulfate of potash magnesia (0-0-22, 11% Mg) to provide 20 to 30 lb of magnesium per acre. If magnesium deficiency occurs during the growing season, apply Epsom salts (11% Mg) at a rate of 2 to 4 lb/acre.

—Use of Plant Tissue Sampling

You can check to see whether a crop is receiving sufficient nutrients by collecting tissue samples and having them analyzed. Be careful to collect representative samples and provide adequate information about growing conditions. When trying to diagnose a problem, take separate samples from both normal- and abnormal-looking plants, and collect soil samples from each area.

Other Sources of Fertilizer Information

NCSU Horticultural Leaflets:
www.ces.ncsu.edu/depts/hort/hil/veg-index.html

The current *N.C. agricultural chemicals manual*: ipm.ncsu.edu/agchem/agchem.html

Vegetable crop guidelines for the southeastern U.S., published by the N.C. Vegetable Growers Association

Sustainable practices for vegetable production in the South:
www.cals.ncsu.edu/sustainable/peet/

NOTE 7: Fertilization of Trellised and Staked Tomatoes

(revised September 2005) (currently in process of revision)

Tomatoes, like many vegetables, require a high level of fertility for desired production. One of the most critical aspects of soil fertility associated with tomato culture is correction of soil acidity by lime application. A soil pH of 6.5 promotes root system health and plant nutrient availability throughout the season.

Low soil pH can be harmful to plants. It increases the availability of elements like aluminum and manganese that can be toxic to plant roots. It decreases availability of essential nutrients like calcium and magnesium. As a result, it increases the tendency for blossom-end rot.

When the soil pH is around 6.5, tomatoes take up enough calcium and magnesium for optimal plant growth and fruit development. Magnesium levels are most often a concern when tomatoes are grown on light-colored, sandy soils. When soil pH is low, the best way to provide enough calcium and magnesium is to apply lime.

Lime Sources

For agricultural purposes, there are two types of lime: calcitic and dolomitic. Calcitic lime is calcium carbonate ($CaCO_3$). It contains no magnesium. Dolomitic lime is a mixture of calcium and magnesium carbonates ($CaMg(CO_3)_2$) and contains a minimum of 120 lb magnesium per ton.

Most agricultural lime available in North Carolina is dolomitic. Generally, it is preferred because it supplies magnesium. However, when magnesium levels are adequate, especially on the fine-textured soils of the mountains and piedmont, calcitic lime can be used without concern.

Low levels of magnesium are indicated on the soil test report by a "$" symbol in the Mg column of the “Recommendations” section. When soil pH and magnesium are both low, apply dolomitic lime. If the soil report indicates that magnesium is low but lime is not needed, apply magnesium at a rate of 25–30 lb/acre from a readily soluble source such as sulfate of potash magnesia (0-0-22, 11.5% magnesium).

Lime Rates, Timing and Application

The soil test report lime recommendation is given in units of tons per acre. This amount should raise soil pH to about 6.5. However, the actual pH obtained will vary depending on soil texture, lime quality (particle size, neutralizing value) and method of application (depth of incorporation).

If a soil test recommends lime, apply it as soon as possible to allow time for soil acidity to be neutralized. For the best results, use a high-quality, agricultural-grade lime and incorporate it thoroughly into the upper 6 to 8 inches of soil. Since lime is not very water soluble, it does not move easily down into the soil. Therefore, spreading lime on the soil surface after bedding or planting is not very effective and should only be done to correct a serious pH problem that is diagnosed during the growing season.

Soil texture affects the lime requirement. Very coarse-textured soils in the coastal plain may need lime every year. Fine-textured soils and those with high levels of organic matter typically require lime every two to three years. Where high rates of acid-forming nitrogen fertilizers are used, lime may be needed more often.

Preplant Fertilization

—Piedmont and mountain soils

For determinant varieties like 'Mountain Pride', broadcast 40–60 lb N per acre and all of the recommended P_2O_5 and K_2O. Incorporate the fertilizer into the soil. Sidedress the remaining nitrogen (50 lb/acre) when the first fruit clusters are formed. The total nitrogen rate ranges from 90 to 120 lb/acre.

For stimulation of early growth, apply a water-soluble, high-phosphate starter fertilizer at transplanting. Use 2–4 lb material per 100 gallons of water. Since the starter rate is so low, do not reduce the rate of the recommended fertilizer to account for it.

—Coastal plain soils

Follow the preplant and sidedress fertilization schedule recommended for the mountain and piedmont regions. The production season is shorter in the coastal plain due to the effects of high atmospheric temperatures on maturity.

Nitrogen and potassium leach from sandy coastal plain soils when rainfall is heavy. When this occurs, apply additional N as well as an equivalent amount of K_2O. For example, if you sidedress with 50 lb N per acre, include 50 lb K_2O. Base the need for additional nitrogen and potassium on current soil tests and plant tissue analyses.

Special Nutrient Concerns

—Boron

Tomatoes grown at the recommended soil pH of 6.5 may show signs of boron deficiency. Lack of boron causes brittle stems, dieback of growing tips, and deformed fruit. To alleviate this problem, apply boron at a rate of

- 2 lb/acre on piedmont and mountain soils and
- 1 lb/acre on sandy coastal plain soils.

To ensure uniform distribution, mix the boron fertilizer thoroughly with your broadcast fertilizer.

If soil application is not practical, apply boron to the foliage according to your regular spray schedule. Use 1–2 lb/acre of a 20.5% B material at two-week intervals for a total of three applications. Spray applications should start two to three weeks after transplanting.

Plants need boron only in very small amounts. Excessive rates can be toxic. Therefore, calculate the rate of application carefully, using this equation:

$$\begin{aligned} &(\textit{lb boron needed per acre} \times 100) \\ &\div \textit{\% boron in fertilizer} \\ = \ &\textit{lb boron fertilizer required per acre.} \end{aligned}$$

—Sulfur

Like nitrogen, sulfur is also subject to leaching on sandy soils. On the soil test report, a sulfur index (S-I) of 25 or below is considered low. When this is the case, apply 15–30 lb/acre of sulfur at planting. Use the higher rates on sandy soils or where a history of sulfur deficiency is known.

Sulfur deficiency and nitrogen deficiency look very similar and often occur together. If there has been a lot of rain and nitrogen is low, sulfur is probably low as well. Plant tissue analysis is the best way to identify a deficiency.

—Blossom-end rot and calcium

As already mentioned, tomatoes have a high calcium requirement. Applying lime according to soil test recommendations will usually meet this need. However, it may be beneficial to apply additional calcium to fields with very sandy soils if cation exchange capacity (CEC) values on an NCDA&CS soil test report are less than 3.0. In such cases, sidedress with calcium nitrate.

During dry periods, blossom-end rot may occur even when calcium levels are adequate. Try to prevent water stress by mulching plants and irrigating, if possible.

If blossom-end rot occurs, treat it with a foliar application of calcium. Mix the solution at a rate of 4 lb of calcium nitrate or calcium chloride per 100 gallons of water. Apply two to three times a week, beginning when the second fruit clusters bloom. Other products, such as calcium chelates, may also be available. As with any products, follow label directions.

NOTE 8: Fertilization of Greenhouse Tomatoes (revised March 1997)

Lime

A high calcium level in the soil is essential for optimum growth of tomatoes and prevents blossom-end rot. The lime rate recommended on your soil test report should raise the soil pH to around 6.5 and maintain a high level of calcium.

The desired calcium level for greenhouse tomatoes ranges from 55 to 60%. If no lime is recommended and calcium is below 55%, broadcast 8–10 lb of gypsum per 1000 ft^2. Lime and gypsum applications are most effective when incorporated into the soil prior to transplanting.

When magnesium is low, *$* appears in the Mg column of the *Recommendations* section of the soil test report. If *$* is present and lime is recommended, apply dolomitic lime. Otherwise, apply 10 lb of Epsom salts per 1000 ft^2.

High rates of potassium and ammonium nitrogen can interfere with magnesium uptake even when soil magnesium levels appear adequate. If magnesium deficiency symptoms appear, spray plants with 1.0 lb of Epsom salts in 10 gallons of water. Spray enough to cause run off.

Preplant Fertilization

Broadcast and incorporate 2 lb nitrogen per 1000 ft^2 and all the recommended P_2O_5 and K_2O.

It can be detrimental to apply more nitrogen and potassium than recommended. High soluble salts burn seedlings. Excess nitrogen delays fruit set. If either of these situations occurs, cease fertilizer application and maintain adequate soil moisture.

When plants begin to bloom, use plant tissue analysis to determine the need for fertilizer supplements. Follow the guidelines outlined in the next section.

Supplemental Fertilization

Four weeks after transplanting and at 4-week intervals thereafter, sidedress with 0.75 lb N and 1.0 lb K_2O per 1000 ft^2. Continue sidedressing until plants top out or set the last fruit cluster. Spread sidedressed fertilizers in a broad band at least 4–6 inches away from plants and water into the soil.

The following materials supply 0.75 lb nitrogen and/or 1.0 lb K_2O per 1000 ft^2:

- 1.5 lb ammonium nitrate (33.5-0-0) & 2.3 lb potassium nitrate (13-0-44) [supplies N & K_2O],
- 2.2 lb ammonium nitrate (33.5-0-0) [supplies N only],
- 2.0 lb potassium sulfate (50% K_2O) [supplies K_2O only],
- 3.0 lb calcium nitrate (15.5% N) & 2.3 lb potassium nitrate (13-0-44) [supplies N, K_2O & Ca].

Monitor the crop's need for supplemental fertilizer by taking timely soil and plant tissue samples. Begin taking weekly plant tissue samples at first bloom and continue until plants top out. Take soil samples at monthly intervals and at least 8 days before the monthly scheduled fertilizer application. Soil monitoring assesses the need for the scheduled fertilizer application and indicates any potential soluble-salt buildup.

If monitoring indicates adequate nutrient levels and no immediate need for fertilizer, alter your schedule to sidedress at 5-week, instead of 4-week, intervals. Too much fertilizer causes soluble-salt buildup and increases the potential of blossom-end rot. Excessive nitrogen, in particular, promotes vegetative growth at the expense of fruit set.

Blossom-End Rot

This tomato fruit problem can be caused by high soluble salts, low soil calcium or inadequate soil moisture. When it occurs, remove the affected fruit and spray the remaining fruit with a solution of calcium chloride at the rate of 2 to 4 level tablespoons per gallon of water. Direct the spray toward the fruit.

Repeat this treatment at 7- to 10-day intervals for at least two or three applications. Make sure soil moisture is adequate.

Plant Tissue Sampling

Take soil and plant tissue samples from at least ten plants within each unit or bay. Collect the fifth leaf down from the growing tip. From each tissue-sampled plant, take a core of soil from the root zone.

Label the matching soil and plant tissue samples with identical numbers or letters. Fill out the information sheet in detail, specifying fertilizer treatments, stage of plant growth, etc. Boxes, envelopes and information sheets for soil and plant samples are available through local agricultural advisors or the NCDA&CS Agronomic Division.

Micronutrients (B, Mn, Zn & Cu)

Boron is essential for fruit set and quality. Apply 6 oz of borax (11% B) per 1000 ft^2 along with the preplant fertilizer treatment. Take care not to exceed this rate because too much boron is detrimental to plants.

On the soil test report, a *$* in a micronutrient column of the *Recommendations* section indicates that soil levels of that nutrient are low. When this is the case, apply the indicated amount of the appropriate nutrient for each 1000 ft^2:

Mn	13 oz manganese sulfate (28% Mn)
Zn	6 oz zinc sulfate (36% Zn)
Cu	6.4 oz copper sulfate (25% Cu).

Use trace element materials that are totally water soluble and easily incorporated into the soil.

Soluble-Salt Index (SS-I)

The rate of fertilizer, type of growth media, weight-to-volume ratio (W/V), cation exchange capacity (CEC), water-holding capacity and temperature all influence the soluble-salt index. The rate of fertilizer has the greatest effect and is directly correlated with levels of soluble salts.

Plants grown in an artificial media, such as peat-vermiculite mixes, require and will tolerate a much higher salt index than those grown in mineral soils. This is because artificial soils have a higher water-holding capacity.

Therefore, interpreting the soluble salt index depends on soil type. Table 1 shows how one SS-I value can have different implications for different media. Based on the soluble salt levels shown in Table 1, take the appropriate action indicated in Table 2.

Table 1. Soluble-salt hazards based on soil media type

	Soluble-Salt Index (SS-I) Ranges			
Media Type	**Low**	**Medium**	**High**	**Very High**
peat-lite mixes	0–40	41–100	101–180	180+
silt-clay loam	0–30	31–75	76–135	135+
sandy loam	0–23	24–51	52–95	95+
pine bark	0–12	13–26	27–50	50+

Table 2. Actions to remedy soluble-salt levels

Soluble-Salt Level	Action Required
Low	The media needs additional fertilizer. The effect of salt on the plants is negligible.
Medium	Fertilize plants only if the SS-I is at the low end of the range.
High	Germination and seedling injury may occur if the SS-I is at the high end of the range. Otherwise, levels are satisfactory.
Very High	Do not add fertilizer or let the media become dry. Water enough to cause leaching if the SS-I is at the high end of the range. Leach extensively if it is over this range.

NOTE 9: Soil Analysis of Growth Substrates for Greenhouse Crops (revised January 2006)

In addition to soil testing, best management practices for any greenhouse crop include having irrigation source water tested (solution analysis) well in advance of production. This approach allows time to make any necessary adjustments to substrate or source water before it comes into contact with plants.

During production, plant tissue analysis and solution analysis of pour-thru leachate are the appropriate tests for diagnosis of nutrient-related problems. NCSU Horticulture Information Leaflet 590 describes the pour-thru sampling procedure and is available online at www.ces.ncsu.edu/depts/hort/floriculture/cfr/index.htm.

The primary purpose of soil testing in a greenhouse situation is to evaluate the quality of bulk growth media prior to production. Soil testing is geared toward providing reliable information about nutrient levels and properties of mineral soil, but it does have some limited usefulness with regard to soilless media (perlite, vermiculite, peat, bark, compost, sand and/or mixtures of these). The key items that are always important in a "soil" analysis of a greenhouse substrate are pH and soluble salt levels. These values must be within acceptable ranges before a crop is planted.

Greenhouse crops can include houseplants, bedding plants, seasonal flowers, perennial flowers, vegetables and herbs. Fertilizer and pH requirements vary greatly, depending on crop, type of substrate and production method. For this reason, the soil test report does not provide lime and fertilizer recommendations for specific crops. Each grower must decide when adjustments need to be made based on a comparison of soil test report values and the optimum fertility requirements given in crop production manuals.

pH/Lime

Most plants grow best in a substrate with a pH of 5.5–6.5. For these, a target pH of 6.0 is usually recommended. However, some plants are more suited to acid soils with a pH of 5.0–5.5. Refer to production manuals for a crop's optimum pH, then use the formula in **Figure 1** to calculate the lime requirement, if necessary.

Figure 1. Formula for calculation of lime requirement

$$\frac{\textit{desired pH} - \textit{soil pH}}{6.6 - \textit{soil pH}} \times Ac \times cf = \textit{rate of lime to apply}$$

where

Ac is the soil test report acidity value and *cf* is the appropriate conversion factor for the desired rate of application: use *cf* = 1.9 to obtain lb per yd^3 and *cf* = 46 for lb per 1,000 ft^2.

For example, *if* *soil test pH* = 5.0, *Ac* = 1.5 and *desired pH* = 6.0, *then* you should apply

$$\frac{6.0 - 5.0}{6.6 - 5.0} \times 1.5 \times 1.9 = 1.8 \text{ lb per yd}^3$$

or

$$\frac{6.0 - 5.0}{6.6 - 5.0} \times 1.5 \times 46 = 43 \text{ lb per 1,000 ft}^2$$

Soluble Salt Index (SS-I)

Since most plant nutrients in fertilizers are formulated as salts, the SS-I is an indication of the fertility level of the substrate. When fertility is too high, salts can cause injury to plant roots. Composition of the substrate, moisture level, texture, temperature and other factors determine the potential for SS-I problems. As a general rule, plants growing in substrates with high cation exchange (CEC) and water-holding capacities can tolerate higher fertility and soluble salt levels.

Table 1 indicates the relative salt hazard to a crop based on substrate type and SS-I value. Find the hazard level indicated by the SS-I value on your soil test report, and take the action indicated in **Table 2**.

Nutrient Level Values & Recommendations for Soil-based Media

Soil test nutrient analyses are not generally meaningful for soilless substrates. Nutrient level measurements can be misleading for these types of media. Assume all nutrients are to be supplied by the fertilizer solution.

For soil-based substrates, nutrient level values and recommendations are relevant. Refer to **Figure 2** for formulas to calculate application rates for dry or liquid fertilizers.

The nutrient concentrations for phosphorus (P), potassium (K), sulfur (S), manganese (Mn), zinc (Zn) and copper (Cu) are reported as indices (P-I,

Table 1. Salt hazard by substrate type

	Soluble-Salt Index (SS-I) Ranges			
Media Type	**Low**	**Medium**	**High**	**Very High**
peat-lite mixes	0–40	41–100	101–180	180+
silt-clay loam	0–30	31–75	76–135	135+
sandy loam	0–23	24–51	52–95	95+
pine bark	0–12	13–26	27–50	50+

Table 2. Soluble-salt guidelines

Salt Level	Action Required
Low/Medium	The effects of salt on plants is negligible.
High	Germination and seedling injury may occur if the SS-I is at the high end of therange. Otherwise, levels are satisfactory.
Very High	Do not add fertilizer or let the media become dry. Water enough to causeleaching if the SS-I is at the high end of the range. Leach extensively if it is over this range.

K-I, S-I, Mn-I, Zn-I, Cu-I). In general, an index value less than or equal to 10 indicates a very low nutrient level; 11–25, low; 26–50, medium; 51–100, high; and 100+, very high. For the micronutrients Mn, Zn and Cu, index values greater than 25 indicate sufficient levels for plant growth. Because availability indices (Mn-AI, Zn-AI) take into account the effect of soil pH, these values are better indicators of sufficiency than Mn-I and Zn-I.

Nitrogen (N). NCDA&CS soil tests do not measure N concentration, and the report does not recommend a rate for N. Most greenhouse crops need 3–6 lb N per 1,000 ft^2 or 0.125–0.250 lb N per yd^3 for the production cycle. Growers should refer to a reliable production manual for the specific crop.

Phosphorus (P) & Potassium (K). Soil test recommendations for P and K are provided in units of lb/1,000 ft^2 of P_2O_5 and K_2O, respectively. To convert these rates to lb/yd^3, divide by 24. Take into account the amount of P_2O_5 and/or K_2O that will be applied if a complete fertilizer such as 20-10-20 is used as the nitrogen source.

Magnesium (Mg). If a *$* symbol appears in the Mg column of the *Recommendations* section on the soil test report, levels of Mg are low. When *$* is present and the pH is low, apply dolomitic lime. However, if lime is not needed, supply Mg by adding 5 lb Epsom salts (0.5 lb Mg) per 1,000 ft^2. For established plants, apply Mg along with other fertilizer treatments. In a constant feed program, inject 35–50 ppm Mg using a source such as Epsom salts.

Sulfur (S). Plant tissue analysis is the most reliable test for determining sulfur status in the crop. When the S-I is less than or equal to 25 for soil-based substrate, an application of 0.5 lb S per 1,000 ft^2 may be beneficial to the crop. For a continuous-feed program in soilless substrates, 35–50 ppm S is recommended.

Micronutrients. A *$* symbol in the Mn, Zn or Cu column of the *Recommendations* section of the soil test report indicates low levels of these nutrients. Application may or may not be necessary. It is best to monitor status of micronutrients with plant tissue analysis.

Figure 2. Formulas for calculating dry or liquid fertilizer rates

Dry fertilizer

$$\frac{\textit{rate of nutrient needed}}{\textit{\% nutrient in fertilizer}}$$

For example, *if* the soil report recommends 6.0 lb /1,000 ft^2 K_2O and you have a 13-0-44 fertilizer (13% N, 0% P_2O_5 and 44% K_2O), *then* you should apply 13.6 lb fertilizer per 1,000 ft^2.

$$6.0 \text{ lb } K_2O\text{ /1,000 ft}^2 \div 0.44\ K_2O = 13.6 \text{ lb /1,000 ft}^2$$

Liquid fertilizer

$$\frac{\textit{ppm nutrient needed}}{(\textit{\% nutrient in fertilizer} \times 75)}$$

For example, 6.7 oz of Epsom salts (10% Mg) in 100 gallons of water will supply 50 ppm Mg.

$$50 \text{ ppm Mg} \div (0.10 \text{ Mg} \times 75) = 6.7 \text{ oz /100 gallons}$$

NOTE 10: Fertilization of Commercial Flowers

(discontinued)

NOTE 10: Fertilization of Commercial Flowers

(discontinued)

NOTE 11: Fertilization of Nursery Crops—Container and Field

(revised July 1995)

The goal of plant production is to grow vigorous and healthy plants in the shortest period of time. Attaining this objective depends on application of proper amounts of lime and essential nutrients. Soil testing provides a means for determining lime and fertilizer rates.

Lime Requirement

A proper soil or media pH is essential for successful plant growth. Lime neutralizes soil acidity and provides the calcium and magnesium essential for plant growth. There is no substitute for lime for neutralizing soil acidity. Lime also provides a better environment for microbial activity required for transforming nutrients to forms that plants can utilize.

There are two types of lime: calcitic and dolomitic. Calcitic lime is composed of calcium carbonate and contains little or no magnesium. Dolomitic lime is composed of a mixture of calcium and magnesium carbonates and contains a minimum of 120 lb of magnesium per ton. For maximum benefit, mix recommended lime into the soil or media prior to planting. Surface application of lime should not exceed 1.0 ton per acre (50 lb per 1000 ft^2 or 50M) on established field plantings. Wait six months before applying additional lime.

The pH requirement for container and field-grown crops varies widely. The formula below provides a means to calculate the lime rate necessary to achieve the desired pH. Soil pH and acidity (Ac) appear on the soil test report.

$$[(\textit{desired pH} - \textit{soil pH}) \div (6.6 - \textit{soil pH})] \times Ac = \text{tons lime per acre}$$

Conversion Factors

M = lb per 1000 ft^2
tons lime per acre × 46 = lb lime per 1000 ft^2
lb lime per 1000 ft^2 ÷ 24 = lb lime per yd^3
tons lime per acre × 1.92 = lb per yd^3

Micronutrients

A *$* appears in the *Recommendations* section when the index for manganese (Mn), zinc (Zn) or copper (Cu) is below 25. The *$ Note* that comes with your soil test report provides information on correcting low micronutrient levels. Most field soils contain an adequate amount of micronutrients. Pine bark mixes generally contain adequate levels of manganese and zinc but are usually low in copper.

Broad-spectrum applications of micronutrients can be unnecessary as well as harmful. Therefore, base micronutrient applications on soil test recommendations. If using a composite micronutrient source, apply the lowest rate necessary to meet plant requirements.

Container-Grown Plants

A mixture of pine bark and sand is the media used for most container-grown plants. Native pine bark, which is the major component, has a relatively low nutrient content. Successful production in this media requires supplementing with fertilizers. The challenge is to maintain adequate nutrient levels without creating a potential soluble salt problem.

The target pH for most field and container-grown plants ranges from pH 5.5 to 6.0. Nursery crops grow well in a pine bark and sand mixture at pH 5.5. The pH of native pine bark, however, ranges from 4.0 to 5.0. Application of dolomitic lime raises the pH to a more suitable level and provides the calcium and magnesium essential for plant growth. Native bark generally contains low phosphorus, calcium and magnesium with appreciable amounts of potassium, manganese and zinc.

Leaching of nitrogen, phosphorus and potassium is a common problem associated with pine bark and sand media. Nutrient leaching is most prevalent during periods of heavy rainfall or high irrigation demand. Sand that is coated with clay reduces loss of phosphorus and potassium. The clay fraction provides sites that attract and hold nutrients against leaching. Use of slow-release fertilizers also reduces leaching of nitrogen, phosphorus and potassium. The release of these nutrients depends on nutrient source, temperature, moisture and method of encapsulation.

Rates of application depend on manufacturer guidelines and grower experience.

Field-Grown Plants

Lime and phosphorus do not move readily through the soil. Therefore, it is best to broadcast and mix them into the soil prior to planting. Incorporation enhances soil reaction and nutrient uptake by plants.

Nitrogen and potassium are mobile in soils. Therefore, surface applications are effective. Apply fertilizers 6–8 inches from plants to reduce the risk of salt injury. Split applications of nitrogen and potassium also minimize the effects of leaching on sandy soils. Nitrogen recommendations are as follows:

- First Year: Apply 50 lb N per acre prior to bud swell (approximately 0.5 oz N per plant).

- Second and Subsequent Years: Apply 80–120 lb N per acre per year. Apply two-thirds prior to bud swell and one-third in early June. Do not apply nitrogen after July 1 since late growth may be more subject to winter injury.

Nitrogen rates may vary from rates shown above for high population plantings. Factors for converting nitrogen from lb per acre to oz per tree are as follows:

- lb N per acre ÷ 43.56 = lb N per 1000 ft^2,
- lb N per 1000 ft^2 ÷ ft^2 per tree = lb N per tree, and
- lb N per tree × 16 = oz N per tree.

Nursery Seedling Beds

Mix recommended lime, phosphorus and potassium into the soil before planting. Apply lime several weeks in advance to allow time for soil acidity to be neutralized.

Apply nitrogen after plants emerge to prevent damage from soluble salts. Use 25–30 lb N per acre and follow by irrigation if soil moisture is low. Use split applications for the remaining nitrogen depending on rainfall and plant growth.

On established plants, apply fertilizer in early spring before growth begins. On sandy soils, split applications of nitrogen and potassium reduce leaching losses. On sandy soils, sulfur-containing fertilizers are often beneficial.

Soluble Salts (SS-I) Interpretation

Over-application of fertilizers or inadequate watering can cause salt injury. Salt damage depends on the type of media, moisture content, temperature and plant tolerance. The soluble salt ratings for different media given in Table 1 can be interpreted as follows:

Low: Needs additional fertilizer, no effect of salt on plant growth.

Medium: Fertilizer can be applied at the lower end but should be adequate near the top.

High: Germination and seedling growth affected as salt index increases within this range.

Very High: Apply no fertilizer, and water enough to cause salts to leach.

Additional information on lime and fertilizer requirements for nursery crops is available from local agricultural advisors. If there is reason to suspect a nutritional problem, collect matching soil and plant samples. Send them to the laboratory for analysis.

Table 1. Soluble-salt hazards based on soil media type

	Soluble-Salt Index (SS-I) Ranges			
Media Type	**Low**	**Medium**	**High**	**Very High**
peat-lite mixes	0–40	41–100	101–180	180+
silt-clay loam	0–30	31–75	76–135	135+
sandy loam	0–23	24–51	52–95	95+
pine bark	0–12	13–26	27–50	50+

NOTE 12: Fertilization of Forage and Pasture Crops

(revised October 2006)

Production of quality forage requires a balanced pH and nutrient regime. Soil testing is the best way to determine lime and fertilizer requirements. Submit soil samples from established pastures, hay meadows and silage fields every one to three years to meet yield goals and animal nutritional requirements.

Lime

Your lime recommendation is designed to neutralize soil acidity. When possible, till recommended lime into the soil. On no-till sites or established fields, surface applications are beneficial; however, do not apply more than 1.0 ton per acre at one time.

If recommendations exceed 1.0 ton per acre, apply the excess the following year. Lime rates depend on the current and target soil pH for the specified crop. The target pH for forage crops grown on mineral soils ranges from 6.0 to 6.5.

There are two types of agricultural lime. Calcitic lime is calcium carbonate ($CaCO_3$). Dolomitic lime is a mixture of calcium and magnesium carbonates [$CaMg(CO_3)_2$] and contains a minimum of 120 lb of Mg per ton. Dolomitic lime is an economical source of Mg and reduces the risk of grass tetany in livestock.

Another potential source of lime is lime-stabilized sludge. Since calcitic lime is used with these sludge materials, soil Mg levels should be monitored. When Mg is needed, 25–30 lb per acre are adequate.

For establishment of perennial grasses, NCDA&CS recommends enough lime to raise the pH to 6.5 on mineral soils. This initial application, which is tilled into the soil, fosters a higher pH that allows for a longer production period before additional lime is needed. After establishment, a target pH of 6.0 is appropriate for forage production on mineral soils.

Phosphorus (P), Potassium (K) & Sulfur (S)

Soil testing will accurately predict phosphate (P_2O_5) and potash (K_2O) needs. The following are general guidelines for fertilizing forage crops at planting and after establishment. Specific nutrient suggestions are given later by crop.

Prior to establishing any forage, refer to current soil recommendations for rates of P_2O_5 and K_2O. If P_2O_5 is needed, till it into the plow layer prior to planting, if practical, since it does not move easily into soil. Incorporation is especially critical for any soils with medium or low P-I values ($<$ 50), especially on perennial crops that are to be productive for several seasons. On soils with high P-I values where less P_2O_5 is recommended, incorporation is not as critical. Commonly available sources of P are triple superphosphate (0-46-0), superphosphate (0-20-0) and diammonium phosphate (18-46-0).

For established crops, apply P_2O_5 before plants begin new growth. Do not apply it prior to rainfall events if not incorporating it because runoff is likely. Also, do not apply P_2O_5 if it is not recommended. Doing so may lower economic returns and lead to excessive accumulation in the soil. Special considerations related to P use may apply in river basins designated as Nutrient Sensitive Waters.

When K_2O is recommended for new plantings, you can apply the full rate and incorporate it with P_2O_5 on medium and fine-textured soils. K may leach on sands that have low cation exchange capacities (CEC values) and low water-holding capacities, especially in seasons with excessive rainfall. Split applications may be beneficial to increase use efficiency. On such sites, apply half the recommended rate at planting. Apply the rest at midseason of new growth or split it into two equal applications during the growing season.

For crops established on medium or fine-textured soils, you can apply all K_2O just before new growth begins. On sands, apply half at the beginning of the growing season and the remainder at midseason. Alternatively, you can apply K_2O in equal applications after each cutting or at each nitrogen (N) application, depending on the crop. Commonly available sources of K are muriate of potash (0-0-60), potassium sulfate (0-0-50) and potassium magnesium sulfate (0-0-22).

Sulfur is usually present in adequate amounts in medium- and fine-textured soils. Like K, it is subject to leaching on sands, especially in seasons with excessive rainfall. The soil test report gives a sulfur recommendation whenever S-I < 25. On crops receiving N applications, apply any recommended S when N is first applied. Since S leaches readily, it may be adequate at the time of the report but be limiting later during the season. Plant tissue analysis can be used in-season to test for sufficiency.

Animal Waste as a Nutrient Source

Soil application of poultry and animal wastes provides nutrients such as N, P_2O_5, K_2O and S. Use of livestock wastes reduces the need for commercial fertilizers and disposal of waste products. Waste products should be analyzed for nutrient content prior to application. The NCDA&CS Agronomic Division provides a waste analysis service that helps determine suitable applications rates.

Always use a current soil test report as a guide in animal and poultry waste management plans. On farms governed by water quality or waste regulations, base N and P_2O_5 rates on nutrient management guidelines. Off-site movement of both N and P can negatively affect water quality. Also, excess N from manure causes overabundant vegetative growth, which promotes plant disease and causes nitrate poisoning in livestock.

Animal wastes may contain high levels of micronutrients (zinc and copper) so soil levels should be monitored.

Alfalfa

Alfalfa is very sensitive to acid soils. It requires a soil pH of at least 6.5 for optimum growth. Adequate Ca levels are also essential for high yields. Lime not only neutralizes soil acidity but also provides essential Ca and Mg.

Molybdenum (Mo), a micronutrient essential for symbiotic N fixation (nodulation), becomes more available as soil pH increases. However, some soils are inherently low in Mo. Under such conditions, apply Mo to the soil at the rate of 0.25–0.5 lb per acre.

When seeding legume forage crops, use an inoculant containing Mo. On established fields, a foliar application of 3.0 ounces of Mo in 25 gallons of water per acre will correct a deficiency. Apply foliar Mo in spring before new shoots are 2–3 inches high.

Alfalfa also requires high levels of boron (B). Since most soils are low in B, broadcast 3.0 lb per acre for establishment and 2.0 lb per acre per year for maintenance. There is no reliable soil test for

Mo and B, but plant tissue analysis will identify deficiencies. If problems develop during the growing season, submit soil and plant samples for analysis.

Alfalfa requires high soil P and K (P-I, K-I > 50) to sustain yields. The K removed from the soil by the crop must be replenished with fertilizers. Where K is subject to leaching, apply half the recommended K_2O in March. Apply the remainder in June after the second cutting. When leaching is not a concern, apply all the K_2O in fall, in early spring or in split applications.

Clover-Grass Mixtures

Well-balanced clover-grass mixtures that contain tall fescue, orchardgrass, prairiegrass or timothy do not need N. If applied, it promotes competition between clover and grasses and often leads to a pure grass stand. However, if the clover stand is less than 25% and re-establishment of clover is not desired, apply fertilizers as recommended for pure grass stands. Refer to the section **Cool-Season Perennial Grasses** for fertilizer and lime recommendations.

White Clover & Bluegrass

Most clover-bluegrass pastures are grown in the mountains at elevations above 2000 ft. The most prevalent fertility problem is low P. When P_2O_5 and K_2O are recommended, apply the full amounts either in early spring or fall. Although response to P often exceeds response to lime, most mountain pastures are quite acid and would benefit from liming.

A balanced clover-grass stand does not need N. In such a stand, the N supplied by the clover does not promote grass growth to the extent that it competes with clover. However, to shift peak production to an earlier period, apply 50–60 lb N per acre per year in either early August for fall growth or March for early spring growth. Be aware that while early N application enhances grass production, it may have a negative effect on clover unless the grass is properly grazed to a height of less than 8 inches.

Cool-Season Perennial Grasses

The N rates for cool-season grasses—such as fescue, bluegrass, orchardgrass and timothy—range from 100 to 200 lb per acre to allow adjustment for soil type, geographic region and level of production desired for hay and grazing. For tall fescue hay, apply 200 lb per acre on sandy soils and 160 lb per acre on fine-textured soils. On tall fescue pastures for grazing, NCDA&CS recommends 150 lb per acre on sandy soils and 120 on fine-textured soils.

If high yields are not practical or desired, reduce N rates to fit the situation. Apply half the N in mid-February–March and half in mid-August–September. Mid-August is best for western piedmont and mountain pastures. September is best for eastern piedmont and coastal plain pastures.

Table 1 provides guidelines for estimating yield based on general N rates. A given N rate does not guarantee a specific yield due to other limiting factors, such as pH, P, K, rainfall and management.

Warm-Season Annual Grasses

For millet, crabgrass, Sudan grass and Sudan-sorghum hybrids, the NCDA&CS recommends applying approximately 50–70 lb N per acre per year at or before seeding. Apply the remainder in increments of 40–60 lb per acre after each cutting or grazing period.

Warm-Season Perennial Grasses

When establishing common and/or hybrid bermuda or bahia on sandy soils where K leaches, apply only half the K_2O before sprigging or seeding and the remainder at midseason. When plants start to grow, apply 30–40 lb N per acre over the row and another 30–60 lb N per acre when runners appear (6–8 weeks after planting).

To maintain an established bermuda pasture on sandy soils, make split applications of K_2O that coincide with N treatments (3–4 applications per year, depending on the extent of grazing or the number of cuttings). Adequate K is essential to reduce leaf spot, safeguard against winter kill, and optimize yield and quality. Submit soil samples in late summer to find out if K will be needed in the fall.

The N rate for hybrid bermudagrass hay varies with soil type: 220 lb per acre for sandy soils and 175 lb per acre for medium and fine-textured soils. Apply 50–60 lb per acre in April and the remainder in equal increments in June and mid-July or after each cutting.

Grazing: Nitrogen Rate Reduction

During grazing, nutrients are recycled into the pasture. In open-grazing systems, total N rates may be reduced by 25%. Under controlled grazing, a more uniform distribution of animal waste occurs and total N rates may be reduced by 50%.

Table 1. Dry yield (tons/acre) of forage based on nitrogen application (from Green JT 1994, personal communication) *

	Nitrogen Rates (lb/acre)	
Forage Crop	**100**	**200**
Hybrid Bermuda, Gamagrass	2.5–3.0	4.0–5.0
Common Bermuda, Bahia	1.8–2.3	3.0–3.8
Fescue, Orchardgrass, Timothy, Prairiegrass	2.0–2.5	3.5–4.0
Ryegrass (winter annual)	1.5–2.0	3.0–3.5
Small Grain (silage)	1.5–2.0	N/A
Sorghum-Sudan, Millet, Crabgrass	2.0–2.5	3.5–4.5
Sorghum (silage)	3.0–4.0	5.0–7.0
Switchgrass	2.0–4.0	3.0–4.5

* This table is a guide to help select N rates best suited to your soil and management conditions. N rates of 250 lb per acre will increase perennial grass yields on highly productive soils with adequate moisture and intensive management. For more information, see N.C. Agricultural Research Service Technical Bulletin 305, *Production and utilization of pastures and forages in North Carolina*.

NOTE 13: Hybrid Bermudagrass

(discontinued)

NOTE 14: Fertilization of Golf and Other Fine Turf

(February 2007)

North Carolina is a no man's land as far as turf management is concerned. We are too far south for the cool-season grasses and too far north for the warm-season grasses. However, we can capitalize on the situation and use the best grasses of both the north and the south.

The grass you select will depend on the intended use and the degree of management you are willing to supply. In this climatic region, a high degree of skill is necessary to grow any fine turfgrass. Maintaining fertility of the soil is of utmost importance. Our soil testing service is available for this purpose.

The soil test report suggests the amount of lime and fertilizer needed as a corrective treatment. Amounts are given in terms of pounds per 1000 ft^2 for greens and tees and in tons or pounds per acre for fairways and other extensive turf areas.

Establishment

Broadcast the lime, P_2O_5 and K_2O along with 60–80 lb of N per acre (1.5–2 lb N per 1000 ft^2) before seedbed preparation. Proceed with the seeding operation, and follow up with a topdressing of nitrogen as outlined in Table 1.

Maintenance

You can apply lime as a topdressing at any time of year. However, never apply more than 100 lb per 1000 ft^2 or 2 tons per acre unless the lime can be worked into the soil. High rates without incorporation provide little or no immediate benefit.

The recommended rates of P_2O_5 and K_2O, as well as any follow-up maintenance, are intended as corrective treatment. These nutrients can be applied with a topdressing of nitrogen as indicated in Table 1. All of the recommended P_2O_5 can be broadcast at one time. However, if more than 5 lb K_2O per 1000 ft^2 or 200 lb per acre are topdressed, the application should be split and applied at two different times.

During the year following the recommended corrective treatment, topdress as follows:

- *Bent and bermuda greens*
  3 lb P_2O_5 and 4 lb K_2O per 1000 ft^2, applying half of each at the first topdressing with nitrogen in the fall.

- *Tees*
  2 lb P_2O_5 and 3 lb K_2O per 1000 ft^2 split into two applications: half in the spring and half in the fall on the same time schedule.

- *Fairways or other turf areas*
  160–200 lb N, 60–80 lb P_2O_5 and 80–100 lb K_2O per acre split so half is applied in the spring and half in the fall.

For optimal turf fertility management, have the soil tested every two or three years.

Table 1. Maintenance schedule for golf greens

Turf Species	Source of N	Time to Apply	N rate (lb/1000 ft^2) *
bentgrass	slow-release N**	monthly from Mar to Dec	
	or turf mixture	March to June	0.7–1.3
		June to August	0.3–0.4
		August to December	0.7–1.3
bentgrass	soluble N sources	monthly from Jan to Dec	
		January to March	0.5–1.0
		March to June	0.5–1.2
		June	0.5–0.7
		August	0.3–0.5
		September	0.5–1.0
		October to December	0.7–1.2
bermudagrass	slow-release N**	every 3–4 weeks Apr to Sept	
	or turf mixture	April 15 to July	0.7–2.0
		July to August	1.0–2.0
		to September 15	0.5–0.7
bermudagrass	soluble N sources	every 3–4 weeks Apr to Sept	
		April 15 to July	0.2–1.0
		July to August	0.5–1.0
		to September 15	0.2–0.5

* (rate × 100) ÷ percent nitrogen = pounds of material to use.

Example: If 1 lb N is required from a 12-4-8 fertilizer,
then (1 lb N × 100) ÷ 12 = 100 ÷ 12 = 8.3 lb of 12-4-8.

** When slowly available forms of nitrogen are used in colder seasons, it may be necessary to apply ¼ to ½ lb of quickly available nitrogen to improve color. Do not fertilize during hot and humid weather, for instance in July and/or August.

NOTE 15: Fertilization of Pecans & Miscellaneous Nuts and Fruits

(revised April 1997)

Commercial Orchard Establishment

All fruit and nut trees require fertile soil with balanced amounts of plant nutrients. The lime and fertilizer recommended for orchard establishment serve this purpose. Excessive fertilization and placement of fertilizer near roots at the time of setting is a common cause of the death of young trees.

Broadcast the lime, P_2O_5 and K_2O. Plow the fertilizer into the soil as deep as possible. Dig holes of large enough size for the roots, and set the trees.

Fertilize the young trees again in March or April with no more than 0.5 lb of a 14-0-14 grade of fertilizer or its equivalent. Spread it evenly over the soil in a circle 12 inches from the trunk outward to a distance of 3.5 ft from the trunk or slightly beyond the limb span.

Commercial Orchard Maintenance

There are two rather distinct management systems for pecan and other orchard crops:

- management for nuts or fruit only and
- management for the production of an intercrop plus nuts or fruit.

The key to the success of either is the maintenance of a high level of fertility that will promote good nut and fruit yields.

—Nonbearing trees for nuts or fruit only

a. If you applied the rates of lime and fertilizer recommended by a soil test prior to setting, follow this fertilization schedule.

- In the second year, apply 0.14 lb of both N and K_2O (equivalent to 1 lb 14-0-14 per tree). Spread it in a circle starting 1 ft from the trunk and extending outward to 3.5 ft or slightly beyond the limb span.
- In subsequent years up to bearing age, apply 0.07 lb of both N and K_2O for each year of tree age. Spread it in a circle starting 12–18 inches from the trunk and extending outward slightly beyond the limb span.

b. If you set trees without corrective lime and fertilizer treatments, follow this fertilization schedule.

- Broadcast the lime and fertilizer recommended by a current soil test report over the entire area.

  or
- To treat individual trees, apply 0.07 lb of N and K_2O for each year of tree age. Spread it in a circle starting 12–18 inches from the trunk and extending outward slightly beyond the limb span.
- Continue the same individual treatment each year until bearing age.

—Bearing trees for nuts or fruit only

a. Get a new soil test the first year that trees begin to bear. Broadcast the recommended lime and fertilizer over the entire area.

b. To each tree, annually apply 0.25 lb of N and K_2O (equivalent to 2 lbs of 14-0-14) for each inch of trunk diameter at a height of one foot, as follows.

- In February, broadcast half of the fertilizer under and slightly beyond the limb span.

- After fruit set, apply the other half in the same manner.
- If fruit set is light or does not occur, omit the last half of the treatment.
- Test the soil every three to four years.

—Nonbearing trees with intercropping

Intercropping involves growing cash crops between rows of trees. A reasonable spacing between the tree crop and the intercrop lessens the possibility of damage to trees. This management system provides an economic return from the land until the young trees are brought into production.

If you are planning to intercrop, test the soil to determine the lime and fertilizer needs for the companion crop. Usually the rate recommended for the companion crop is adequate for the tree crop as well if it is broadcast over the entire area.

If you apply lime and fertilizer only to the companion crop area, test the soil in the tree-row area separately. You can then follow establishment and maintenance treatments as if the trees were grown alone.

Fruit & Nut Trees around the Home

You can lime and fertilize apricots, cherries, chestnuts, figs, pears, pecans, plums, walnuts and other home orchard crops in much the same manner as commercial pecan orchards. Soil test reports give lime and fertilizer recommendations for yard trees in units of pounds per 1000 ft^2. The initial recommendation contains enough nitrogen for the first year. In subsequent years, follow one of the maintenance schedules for commercial orchards.

Lush vegetative growth and little or no yield usually indicate excessive application of nitrogen. Reduce nitrogen fertilization if new terminal growth of tree limbs exceeds 12–18 inches per year.

Micronutrients

The soil test report expresses levels of the micronutrients manganese (Mn), zinc (Zn) and copper (Cu) as indexes. Levels are adequate if index values are >25.

Uptake of micronutrients by plants decreases as soil pH increases. Deficiencies generally occur when the soil pH >6.2.

Micronutrient availability can be difficult to assess from a soil test alone, especially for zinc. If you suspect a micronutrient problem, collect matching soil and leaf samples. Take such samples only when abnormal growth or symptoms appear.

Take soil samples from around the perimeter of the tree to a depth of 6 inches, staying within the drip line. Collect recently matured leaves from branches of current year's growth. The best time for collecting leaf samples is from mid-July to mid-August.

You can send soil and plant tissue samples to the Agronomic Division laboratory. There is a $4 fee per sample for plant tissue analysis and no charge for soil samples. Sampling supplies are available from the local Cooperative Extension office or the Agronomic Division laboratory in Raleigh.

NOTE 16: Fertilization of Apples (revised April 1994)

Optimal yields of high quality apples depend on establishing and maintaining the proper soil pH and nutrient balance. Since apple production is a long term investment, lime and nutrient requirements should be addressed before planting. Soil testing provides a means for determining the amount of preplant lime and nutrients required to maintain long term production. Plant tissue analysis also provides a means to monitoring the nutrient status and adjusting nutrient applications during the growing season. Used properly, these tools can provide information necessary for successful apple production.

Lime Requirement

Lime recommendations are designed to raise the soil pH to 6.5 for establishment and 6.0 for maintenance. Before establishing an orchard, broadcast the recommended lime, and mix it into the soil as deep as possible. Deep liming is much more effective in neutralizing soil acidity and distributing calcium and magnesium. Lime also contributes calcium necessary to minimize bitter pit.

On established orchards, surface-applied lime is less beneficial and should not exceed 1.0 ton per acre. Lime recommended above 1.0 ton per acre should be applied the following year. Established orchards should be soil tested every three to five years to maintain the desired pH and nutrient balance.

Both calcitic and dolomitic lime are used in apple production. Calcitic lime is composed of calcium carbonate ($CaCO_3$) and contains little or no magnesium. Dolomitic lime is a mixture of calcium and magnesium carbonate ($CaMgCO_3$) and contains a minimum of 120 lb of magnesium per ton. Dolomitic lime provides an economical source of the calcium and magnesium required for apple production.

Supplementing Calcium

Supplementing calcium on established orchards is essential for minimizing bitter pit and production of quality fruit when leaf calcium is low. Bitter pit can be caused by low soil moisture, low leaf calcium, or an imbalance between calcium and potassium within the leaves. Additional calcium can be soil or foliar applied.

Soil application of gypsum is the most effective way to supply calcium on established orchards. Broadcast 20–25 lb of gypsum ($CaSO_4$) per tree around the drip line six to eight weeks before harvest. Gypsum provides more available calcium within the root zone or subsoil than surface applied lime. However, gypsum is not a liming agent and cannot be substituted for lime to raise the pH. Moreover, gypsum will not correct bitter pit caused by extended dry weather for the current crop.

Foliar application is the most effective way to increase calcium for the current growing season. Apply 3 lb calcium nitrate $(CaNO_3)_2$ or 2 lb calcium chloride ($CaCl_2$) per 100 gallons. Use calcium chloride when tissue analyses show a high nitrogen content. Foliar treatments should be made at two-week intervals starting at first cover spray and ending two weeks prior to harvest. Do not spray orchards when air temperature exceeds 80^0F. If leaf burn is observed, reduce the rate of calcium applied.

Phosphate (P_2O_5) and Potash (K_2O)

Soil test data show low phosphorus levels in some mountain soils, particularly where phosphorus has not been applied. For new orchards phosphorus amendments should be incorporated deeply into the soil before trees are set. Deep incorporation enhances root growth and uptake efficiency. On established orchards, however, where incorporation is not practical, surface applications may be appropriate. Since phosphorus does not leach in soils, it will accumulate with time from fertilizer applications and foliage recycling.

In contrast to phosphorus, potassuim levels are generally higher in mountain soils due the presence of natural potassium-bearing minerals. Potassium applied in excess of soil test recommendations can cause competition with calcium uptake and increase the potential for bitter pit. Therefore, potassium application rates should be based solely on soil and plant analysis. Growers should not make blanket applications of high-potassium fertilizers.

Nitrogen Management

Nitrogen affects apple production more than any other nutrient. Excess nitrogen decreases fruit firmness, delays ripening, color development, and causes premature fruit drop. High nitrogen also promotes water sprout and lateral shoot growth, both of which shades productive fruiting branches. Excess vegetative growth also increases pruning costs.

Length of lateral shoot growth is a good indicator of nitrogen supply. When lateral shoot growth exceeds 10–16 inches, nitrogen rates may be too high. Soils high in organic matter contribute to the total nitrogen supply and may require less nitrogen. Other factors that determine nitrogen requirement include tree age, severity of pruning and fruit load.

Nitrogen application on bearing tree should be split to prevent over application when frost damage occurs: apply half in winter and the remainder when the frost date is past and fruit load is determined.

Plant tissue samples taken in mid-July provide the best means for monitoring nitrogen status and determining future requirements. Guidelines for determining nitrogen rates and time of application are shown below.

Establishment (Nonbearing Trees)

Broadcast 1.0 oz N per year of tree age (6–25 lb N per acre) around the drip line 10–12 inches from the base until trees begin to bear fruit (generally 3 to 4 years after transplanting). Apply nitrogen in the spring just prior to bud-swelling. Nitrogen rates may be altered depending on growth response of the previous season.

Maintenance (Bearing Trees)

Trees producing 10–15 bushels require about 1 lb of nitrogen per tree per year (based on 110 trees per acre). For high-density orchards, apply no more than 80–100 lb per acre. However, the final nitrogen rate depends on soil organic matter, production history, current fruit load, severity of pruning and shoot growth.

Apply half the nitrogen during winter dormancy and the remainder after the extent of fruit set is determined. Split applications allow an opportunity to reduce nitrogen rates in years when frost damage reduces fruit set.

Leaf analysis is a useful tool for monitoring nitrogen requirements. When leaf analysis shows excess nitrogen, little can be done for the current year, but adjustments can be made in subsequent years.

Boron (B)

Boron is recommended to reduce cork spot. Make a foliar application of Solubor at 1 lb per 100 gallons at petal fall or first cover spray. Make sure boron is compatible with other tank mixes. Use leaf analysis in July to monitor boron status. Apply 20 lb of borax per acre to the soil (10% B) every four to five years if boron deficiency persists.

Soil and Leaf Analyses

Soil samples for determining lime and fertilizer requirements should be taken several months before establishing an orchard and retaken every three to five years. Samples should be submitted in the fall to allow time for treatment before the next crop. Preplant soil samples should be taken to the depth of 8 inches at random across the orchard for a total of 15–20 subsamples per acre. Soil samples on established orchards should be taken to a depth of 4–6 inches. Leaf samples should be taken every year from July 15 through August 15.

Records of soil, leaf samples, fertilizer applied and production history should be kept on each orchard. These records provide a means for evaluating fertility practices and a basis for making necessary adjustments. For problem diagnosis submit corresponding soil and plant samples from problem areas. Supplies and information for taking samples can be obtained from local agricultural advisors or the laboratory in Raleigh.

NOTE 17: Fertilization of Peaches (revised March 1997)

Most peach orchards are located on the sandier soils of the south central region. Satisfactory performance of peach varieties depends to a great extent on the fertility levels established when the trees are set. In addition, fruit production can be extended several years by attending annually to the nutritional needs of the trees.

Establishment

The lime, P_2O_5 and K_2O recommended for peach-tree-orchard establishment are corrective applications that bring soil fertility into better balance. Magnesium (Mg) needs are usually satisfied by existing soil levels. However, if extra magnesium is recommended, you can apply magnesium sulfate (9.7%), sulfate of potash-magnesia (11%) or dolomitic limestone, if lime is needed.

Broadcast the lime and fertilizer, and plow as deep as possible. Proceed with the setting operation, but do not add more fertilizer. Too much fertilizer placed near the roots at setting is a common cause of the death of young trees.

Fertilize the young trees with a 1-1-1 ratio material in March. Broadcast 0.05 lb of N per tree (0.5 lb 10-10-10) in a circle starting 12 inches from the trunk and extending outward slightly beyond limb span. Repeat in May and again in July. Make the last application by mid-July to avoid excessive vegetative growth in the fall and possible cold injury in winter.

Maintenance

—Nonbearing Trees

a. If you applied lime and fertilizer according to soil test recommendations prior to setting, follow this fertilization schedule:

second year

- In March, apply 0.1 lb of N per tree from a 1-1-1 ratio material (1 lb 10-10-10).
- Spread the fertilizer in a circle starting 12 inches from the trunk and extending outward slightly beyond limb span.
- Every six to eight weeks, apply a 1-1-1 or 1-0-1 ratio material at the rate of 0.1 lb N per tree (1 lb 10-10-10 or 12 oz of 14-0-14). Continue these applications until mid-July on the sandier soils and until early June on the finer textured soils.

third year

- In March, apply 0.15 lb N per tree (1.5 lb 10-10-10 or 1 lb 14-0-14) in the same manner as previously described.
- In May and again in early July, repeat the same nitrogen application, or use 0.5 lb of NH_4NO_3 per tree in May and early July.

b. If you did not apply lime and fertilizer according to soil test recommendations prior to setting, follow this fertilization schedule:

- Have the soil tested.
- Broadcast the recommended lime as soon as possible.
- In early March, broadcast 60 lb of N per acre along with any P_2O_5 and K_2O recommended.

—Bearing Trees

Once trees begin to bear, fertility factors have a large impact on production as well as tree growth. Plant tissue analysis and soil testing together define fertility needs and indicate solutions much better than either alone. Soil tests indicate corrections needed in the soil. Plant analysis measures the effectiveness of fertilization and reveals less obvious nutrient shortages that directly affect performance and yield.

Apply lime, if needed, as soon as possible. If the magnesium level is questionable, use dolomitic lime. Broadcast all the P_2O_5 and up to 60 lb K_2O along with 40 lb N per acre in early March. If the trees are on deep sandy soil, apply 20–30 lb sulfur per acre to prevent a deficiency of this nutrient.

After fruit set, broadcast another 30–40 lb N and any additional K_2O needed. If fruit set is satisfactory, broadcast another 25 lb N per acre in early July. However, if new terminal growth exceeds 12–18 inches, omit the nitrogen in July. If you have planted cover crops, they may need additional fertilizer.

Boron

Peaches grown on sandy soils need about 0.5 lb boron per acre every three years. Because too much boron can be toxic, it may be safer to add boron to one of the spray solutions each year. To do this, add about 0.2 lb boron (1.8 lb 11% B or 1 lb 20% B material) per 100 gallons of spray solution.

Zinc

Deficiencies of zinc, commonly called “little leaf” or “rosette,” occur in peach orchards on some of the sandier soils. In severe cases, the internodes at the end of the twigs are shortened and the older leaves may fall off leaving a clump or “rosette” of chlorotic younger leaves at the top of the shoots.

To correct or prevent zinc deficiency, apply 1 oz zinc per 100 gallons of spray (3 oz $ZnSO_4$) three times at 3-week intervals from May through July 15.

Continual use of excessive rates of zinc can lead to toxic levels in the soil that are difficult to overcome.

NOTE 18: Fertilization of Small Fruits (January 2007)
(to be extensively revised in the coming year)

All fruiting plants require fertile soil with a reasonable balance of nutrients. The lime and fertilizer rates recommended on your NCDA&CS soil test report serve this purpose. Precise fertility management for fruit crops requires plant tissue analyses as well as soil tests. However, some basic nutrient management guidelines for common small fruit crops are provided here.

Blueberries—Establishment

Take a soil sample prior to establishment to determine pH and fertilizer needs. No lime should be applied to blueberries, except in special cases, and then only on the advice of a qualified consultant.

Broadcast any recommended fertilizer prior to preparing the land for setting. Set the plants without further additions of fertilizer. In early April, or after the first flush of growth, broadcast additional nitrogen (N) at the rate of 10–15 lb N per acre using a 1-1-1 or 1-2-1 ratio material (100–150 lb 10-10-10 or 200–300 lb 5-10-5). Repeat the topdressing four to six weeks later with 20–30 lb N from the same 1-1-1 or 1-2-1 ratio material.

Blueberries—Maintenance

a. If you applied fertilizer according to soil test recommendations at the time of establishment, follow this fertilization schedule.

SECOND YEAR

- Prior to bloom, broadcast 20 lb N per acre from a 1-1-1 or a 1-2-1 ratio material (200 lb 10-10-10 or 330 lb 6-12-6).
- Six weeks later, repeat the topdressing, but increase the rate to 30 lb N per acre (300 lb 10-10-10 or 500 lb 6-12-6).
- After another four to six weeks, apply an additional 30 lb N. Nitrogen alone may be applied at this time, but the same mixed material may be used, if desired.

WHEN PLANTS ARE MATURE

- Prior to bloom, broadcast 30 lb N per acre from a 1-1-1 or 1-2-1 ratio material (300 lb 10-10-10 or 500 lb 6-12-6).
- Six weeks later, repeat the prebloom topdressing.
- Any time after harvest or up to mid-July, topdress with an additional 20–30 lb N per acre. Materials containing N only can be used at this time.
- Have the soil tested at least once every three years.

b. If you did not fertilize your blueberry crop according to soil test recommendations at the time of establishment, follow this fertilization schedule.

- Have the soil tested.
- Prior to bloom, broadcast the recommended rates of P_2O_5 and K_2O along with 20–30 lb N per acre.
- For the rest of the season, continue with the appropriate schedule outlined in section **a.** above.

Grapes—Establishment

Broadcast the recommended rates of lime, P_2O_5 and K_2O before plowing. Then proceed with the setting operation without additional fertilizer. After growth starts, sidedress with a 1-1-1 ratio material to supply 0.02–0.03 lb N per plant (4 oz 12-12-12).

Broadcast the fertilizer in a circle 18–20 inches from each vine. Repeat at monthly intervals until July. A 1-0-1 ratio material, such as 14-0-14, may be used for the later topdressing, if desired.

Grapes—Maintenance

a. If you applied lime and fertilizer to your crop at establishment according to soil test recommendations, follow this fertilization schedule.

SECOND YEAR

- In March, apply 0.06 lb N from a 1-1-1 ratio material (0.5 lb 12-12-12) around each vine. Broadcast it in a 12-inch band beginning 24 inches from the vine.
- Repeat monthly until mid-July.

THIRD YEAR

- In early March, broadcast 40 lb N, P_2O_5 and K_2O per acre. Use a 1-1-1 ratio material equivalent to 330 lb of 12-12-12 grade per acre.
- In May, apply another 30 lb N and K_2O per acre (equivalent to about 200 lb of 14-0-14).

WHEN VINES START TO BEAR

- Have the soil tested again.
- Broadcast the recommended lime as soon as possible.
- In early March, apply the recommended rates of P_2O_5 and K_2O along with 60 lb of N.
- In May, broadcast an additional 30 lb N per acre if vine growth is too slow.
- In July, broadcast another 20–30 lb N per acre.

b. If you did not apply lime and fertilizer according to soil test recommendations at establishment, follow this fertilization schedule.

- Have the soil tested.
- Broadcast the recommended lime as soon as possible.
- In early March, apply the recommended rates of P_2O_5 and K_2O along with the appropriate rate of N based on the age of the vines as outlined above.
- Continue with the appropriate maintenance schedule, which includes taking a soil test at least every three years.

Grape vineyards on sandy soils are susceptible to boron (B) deficiency, especially in dry weather and at a soil pH of 6.5 and higher. The application rate should not exceed 1 lb B per acre every two years (10 lb ordinary borax, 11.3% B; or 7 lb fertilizer borate, 14.3% B). Boron can be supplied as a foliar spray each year, if this is more desirable. In this case, the rate should not exceed 0.2 lb B per acre per year (1 lb Solubor, 20.2% B; or 1.7 lb ordinary borax, 11.3% B). Plant tissue tests can be used to determine its need.

Continued use of boron at rates higher than those suggested may lead to an accumulation of toxic amounts in the soil.

Raspberries & Blackberries —Establishment

Broadcast any recommended lime, P_2O_5 and K_2O along with 30 lb N per acre before plowing. Do not add additional fertilizer when plants are set out. In July, topdress with additional nitrogen at the rate of 30 lb per acre.

Raspberries & Blackberries —Maintenance

a. If you limed and fertilized the crop at setting according to soil test recommendations, follow this fertilization schedule.

- In March, broadcast 40 lb N, 40 lb P_2O_5 and 80 lb K_2O per acre.
- In July, topdress with additional N at the rate of 60–80 lb per acre.

b. If you did not lime and fertilize the crop at setting according to soil test recommendations, follow this fertilization schedule.

- Have the soil tested.
- Broadcast any recommended lime as soon as possible.
- In March, apply the recommended rates of P_2O_5 and K_2O along with 40 lb N per acre.
- In July, topdress with N at the rate of 60–80 lb per acre.
- The following year, use the maintenance schedule outlined under **a.** above.
- Have the soil tested at least once every three years.

Strawberries—Establishment

Broadcast the recommended rates of lime, N, P_2O_5 and K_2O before plowing. Do not apply additional fertilizer when you set out plants in the spring. Thirty days after setting, sidedress with 30 lb N per acre. Topdress with another 40 lb N per acre in September.

Strawberries—Maintenance

a. If you limed and fertilized the strawberry crop at establishment according to soil test recommendations, follow this fertilization schedule.

- Soon after harvest in the first bearing year, topdress with 30 lb N, P_2O_5 and K_2O per acre.
- In August, topdress with another 40–60 lb N per acre.
- Before the second bearing year, have the soil tested again.

b. If you did not lime and fertilize the crop at planting according to soil test recommendations, follow this fertilization schedule.

- Have the soil tested.
- Broadcast any recommended lime as soon as possible.
- Soon after harvest, apply the recommended P_2O_5 and K_2O along with 30 lb N per acre.
- In August, broadcast 40–60 lb N per acre.
- In January or February, some N may be needed on extremely sandy soils. In this case, topdress about 20 lb N per acre. However, limit the N applied to avoid excessive vegetative growth before harvest and soft berries.

Part IV. Resource Information

This section contains nineteen tables that provide quick reference for 1) making fertilizer substitutions, 2) determining equivalent fertilizer rates and 3) converting English units to metric equivalents.

Fertilizer Substitutions

Fertilizers recommended on NCDA&CS reports are often commercial agricultural grades, such as those given in Table 4.1. Agricultural dealers that cater to farmers are most likely to have these fertilizers in stock. These grades may not be available at local discount stores or garden centers. Therefore, growers may need to substitute equivalent fertilizers. Table 4.2 provides some substitutions for commonly recommended fertilizer materials.

North Carolina Limestone Specifications

All limestone sold, offered for sale or distributed in North Carolina must show on the label

- a guarantee of percent calcium,
- a guarantee of percent magnesium,
- the percent calcium carbonate equivalent and
- the number of pounds of material that equal one ton of standard lime.

Standard lime has a calcium carbonate equivalent of 90 percent. Each type of lime must meet the screen requirements outlined in Table 4.3. This information must be displayed on the label. For example, with dolomitic lime, 90 percent must pass through a 20-mesh screen and 35 percent must pass through a 100-mesh screen.

Table 4.1 Amounts of fertilizer that provide 1.0 lb of nitrogen per 1000 ft^2.

20 lb of 5-5-5	12.5 lb of 8-8-8
20 lb of 5-10-10	10 lb of 10-10-10
20 lb of 5-10-5	7 lb of 15-0-14
17 lb of 6-6-18	6.25 lb of 16-0-0
16 lb of 3-9-9	2.99 lb of 33.5-0-0
12.5 lb of 9-0-24	

Table 4.2 Nitrogen fertilizer substitutions*

Fertilizer Grade Recommended	Substitute Fertilizers
20 lb of 5-10-5	10 lb of 10-10-10 + 2 lb of 0-46-0
17 lb of 6-6-18	10 lb of 10-10-10 + 3.5 lb of 0-0-60
12.5 lb of 8-0-24	3.0 lb of ammonium nitrate (34-0-0) + 5 lb of 0-0-60
7.5 lb of 15-0-14	3.0 lb of ammonium nitrate (34-0-0) + 1.75 lb of 0-0-60
1.0 lb of nitrogen	3.0 lb of ammonium nitrate (34-0-0)
16 lb of 3-9-9	5.0 lb of 10-10-10 + 2.0 lb of 0-46-0 + 1.5 lb of 0-0-60
10 lb of 5-5-15	5.0 lb of 10-10-10 + 1.5 lb of 0-0-60
3.0 lb of 15-0-14	1.5 lb of ammonium nitrate (34-0-0) + 0.75 lb 0-0-60
0.5 lb of nitrogen	1.5 lb of ammonium nitrate (34-0-0)
6.0 lb of 8-0-24	1.5 lb of ammoniuum nitrate (34-0-0) + 2.5 lb 0-0-60
20 lb of 5-10-10	10 lb of 10-20-20

* Many of the fertilizers suggested on NCDA&CS soil test reports are agricultural fertilizers and may not be found at garden centers or discount stores. A dealer who sells supplies to farmers may be the most likely source for the suggested fertilizers. All amounts of fertilizer listed in this table provide 1 lb of nitrogen per 1000 ft^2.

Table 4.3 North Carolina limestone size requirements

Lime Types	Percent Passing	
	20 mesh	100 mesh
Ground dolomite *	90	35
Calcitic or marl	90	25
Suspended dolomitic	100	80
Pelletized dolomitic §	90	35

* All dolomitic lime must contain a minimum of 6.0 percent magnesium.
§ Pelletized lime must be manufactured in a manner that will cause it to slake down when in contact with water. Pelletized lime has the same neutralizing value as regular agricultural lime.
SOURCE: NCDA&CS Plant Industry Division

Table 4.4 Equivalent fertilizer rates *

Area Rates			Volume Rates	
lb/ 1000 ft²	**lb/ 100 ft²**	**lb/ acre**	**lb/ yd³**	**oz/ yd³**
10	1.0	436	0.42	6.67
15	1.5	653	0.63	10.10
20	2.0	871	0.83	13.28
25	2.5	1089	1.04	16.64
30	3.0	1307	1.25	20.00
35	3.5	1525	1.46	23.36
40	4.0	1742	1.67	26.72
45	4.5	1960	1.88	30.08
50	5.0	2178	2.08	33.28
55	5.5	2396	2.29	36.64
60	6.0	2614	2.50	40.00
65	6.5	2831	2.71	43.36
70	7.0	3049	2.92	46.72
75	7.5	3267	3.13	50.08
80	8.0	3485	3.33	53.28
85	8.5	3703	3.54	56.64
90	9.0	3920	3.75	60.00
95	9.5	4138	3.96	63.36
100	10.0	4356	4.17	66.72
120	12.0	5227	5.00	80.00
140	14.0	6098	5.83	93.28
160	16.0	6970	6.67	106.72
180	18.0	7841	7.50	120.00
200	20.0	8712	8.33	133.28

* 1 acre = 43,560 ft^2; 1 yd^3 = 27 ft^3; lb/yd^3 = (lb/1000 ft^2) ÷ 24;
(lb/1000 ft^2) × 43.56 = lb/acre; 1 lb = 16 oz.

Table 4.5 Properties of fertilizer materials

Material	% Nitrogen	% P_2O_5	% K_2O	Soil Reaction*	lb Lime/ 100 lb N §	Salt Index †
Ammonium nitrate	33.5	0	0	A	180	105
Monoammonium phosphate	11	48	0	A	180	30
Diammonium phosphate	18	46	0	A	180	34
Ammonium sulfate (23.7% S)	21	0	0	A	538	69
Ammonium polyphosphate	10	34	0	A	180	–
Urea	46	0	0	A	180	75
Liquid nitrogen	30	0	0	A	180	–
Calcium nitrate	15.5	0	0	N	0	65
Potassium nitrate	13	0	44	N	0	74
Muriate of potash	0	0	60	N	0	116
Potassium sulfate (18% S)	0	0	50	N	0	46
Sodium nitrate	16	0	0	B	0	100
Magnesium sulfate (10% Mg; 13% S)	0	0	0	N	0	44
Sulfate of potash-magnesia (11% Mg; 22% S)	0	0	22	N	0	43
Nitrate of soda-potash	15	0	14	N	0	19
Normal superphosphate (12% S)	0	20	0	N	0	10
Triple superphosphate	0	46	0	N	0	10
Gypsum (19% S; 22% Ca)	0	0	0	N	0	8

* A = acid; B = basic; N = neutral.

§ lb of lime required to neutralize acid from 100 lb of nitrogen.

† Salt index for equal weights of materials, $NaNO_3$ = 100.

Table 4.6 Fertilizer dilutions necessary (ounces / 100 gallons water) to deliver parts-per-million (ppm) rates*

ppm	Percent Element in Fertilizer										
soln.	**10**	**13**	**15**	**16**	**18**	**20**	**25**	**30**	**33.5**	**46**	**50**
50	6.7	5.1	4.4	4.2	3.7	3.3	2.7	2.2	2.0	1.5	1.3
100	13.3	10.3	8.9	8.3	7.4	6.7	5.3	4.4	4.0	2.9	2.7
125	16.6	12.8	11.1	10.4	9.3	8.3	6.7	5.6	5.0	3.6	3.3
150	20.0	15.4	13.3	12.5	11.1	10.0	8.0	6.7	6.0	4.3	4.0
175	23.3	17.9	15.6	14.6	13.0	11.7	9.3	7.8	7.0	5.1	4.7
200	26.7	20.5	17.8	16.7	14.8	13.3	10.7	8.9	8.0	5.8	5.3
250	33.3	25.6	22.2	20.8	18.5	16.7	13.3	11.1	10.0	7.2	6.7
300	40.0	30.8	26.7	25.0	22.2	20.0	16.0	13.3	11.9	8.7	8.0
350	46.7	35.9	31.1	29.2	25.9	23.3	18.7	15.6	13.9	10.1	9.3
400	53.3	41.0	35.6	33.3	29.6	26.7	21.3	17.8	15.9	11.6	10.7
450	60.0	46.2	40.0	37.5	33.3	30.0	24.0	20.0	17.9	13.0	12.0

* Equivalent units 1.0 lb = 454 g = 16 oz; 1.0 oz = 28.38 g.

The equation for calculating the amount of fertilizer to mix in 100 gallons of water is shown here: *(ppm of desired element)* ÷ (*percent of element* × 0.75) = ounces / 100 gallons.

Table 4.7 Commonly available sources of nitrogen (N)

Source	Formula	% N
Ammonium nitrate	NH_4NO_3	34
Ammonium sulfate	$(NH_4)_2SO_4$	21
Ammonium thiosulfate	$(NH_4)_2S_2O_3$	12
Anhydrous ammonia	NH_3	82
Aqua ammonia	NH_4OH	20–25
Calcium nitrate	$Ca(NO_3)_2$	16
Sodium nitrate	$NaNO_3$	16
Potassium nitrate	KNO_3	13
Nitrogen solutions	varies	19–32
Urea	$CO(NH_2)_2$	45–46

Table 4.8 Commonly available sources of phosphorus (P)

Source	Formula	% N	% P_2O_5
Superphosphate (0-20-0)	$Ca(H_2PO_4)_2 \cdot H_2O + CaSO_4$	–	18–20
Concentrated superphosphate (0-46-0)	$Ca(H_2PO_4)_2 \cdot H_2O$	–	44–52
Monoammonium phosphate (11-48-0)	$NH_4H_2PO_4$	11	48
Diammonium phosphate (18-46-0)	$(NH_4)_2HPO_4$	18	46
Ammonium polyphosphate (10-34-0)	$(NH_4)_3HP_2O_7\ H_2O$	10	34
Phosphoric acid	H_3PO_4	–	55

Table 4.9 Commonly available sources of potassium (K)

Source	Formula	% K_2O
Muriate of potash (0-0-60)	KCl	60–63
Potassium sulfate (0-0-50)	K_2SO_4	50–52
Potassium nitrate (13-0-44)	KNO_3	44
Potassium hydroxide	KOH	83
Potassium magnesium sulfate (Sul-Po-Mag)	K_2SO_4–$MgSO_4$	22

Table 4.10 Commonly available sources of magnesium (Mg)

Source	Formula	% Mg
Dolomitic lime	$CaMg(CO_3)_2$	6–12
Epsom salt (magnesium sulfate)	$MgSO_4 \cdot 7H_2O$	10
Potassium magnesium sulfate (Sul-Po-Mag)	K_2SO_4–$MgSO_4$	11
Magnesium oxide	MgO	50–55
Kieserti (magnesium sulfate)	$MgSO_4 \cdot H_2O$	18

Table 4.11 Commonly available sources of sulfur (S)

Source	Formula	% S
Sulfur	S	90–100
Ammonium sulfate	$(NH_4)_2SO_4$	24
Gypsum (calcium sulfate)	$CaSO_4$•2H2O	19
Epsom salt (magnesium sulfate)	$MgSO_4$•7H2O	13
Potassium sulfate	K_2SO_4	18
Potassium magnesium sulfate (Sul-Po-Mag)	K_2SO_4-$MgSO_4$	22
Superphosphate	$Ca(H_2PO_4)_2 \bullet H_2O + CaSO_4$	12
Ammonium thiosulfate	$(NH_4)_2S_2O_3$	26
Sulfur-coated urea	$CO(NH_2)_2$-S	10

Table 4.12 Commonly available sources of boron (B)

Source	Formula	% B
Boric acid	N_3BO_3	17
Borax	$Na_2B_4O_7 \bullet 10H_2O$	11
Solubor	$Na_2B_4O_7 \bullet 4H_2O$	20.5
	$Na_2B_{10}O_{16} \bullet 10H_2O$	20.5
Fertilizer borate – 48	$Na_2B_4O_7 \bullet 10H_2O$	14–15

Table 4.13 Commonly available sources of copper (Cu)

Source	Formula	% Cu
Copper sulfate (pentahydrate)	$CuSO_4 \bullet 5H_2O$	25
Copper sulfate (monohydrate)	$CuSO_4 \bullet H_2O$	35
Copper oxide	CuO	75
Ammonia base copper	$CuSO_4 + NH_4OH$	8
Copper chelates	Na_2Cu EDTA	13
	Na Cu HEDTA	9
Cupric ammonium phosphate	$Cu(NH_4)PO_4 \bullet 2H_2O$	32

Table 4.14 Commonly available sources of manganese (Mn)

Source	Formula	% Mn
Manganese sulfate (pentahydrate)	$MnSO_4 \cdot 4H_2O$	26–28
Manganese oxide	MnO	41–68
Manganese chelate	Mn - EDTA	5–12
Manganese nitrate (liquid)	$Mn(NO_3)_2$	15
Manganese chloride (liquid)	$MnCl_2 \cdot 4H_2O$	16.8

Table 4.15 Commonly available sources of zinc (Zn)

Source	Formula	% Zn
Zinc sulfate	$ZnSO_4 \cdot 2H_2O$	35
Zinc oxide	ZnO	78–80
Zinc chloride	$ZnCl_2$	31
Zinc carbonate	$ZnCO_3$	58
Ammonia base zinc (liquid)	————	10
Zinc nitrate (liquid)	$Zn(NO_3)_2$	17
Zinc chelates	Na_2Zn EDTA	14
	Na_2Zn HEDTA	9

Table 4.16 Commonly available sources of molybdenum (Mo)

Source	Formula	% Mo
Ammonium molybdate	$(NH_4)_6Mo_7O_{24} \cdot 2H_2O$	54
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	39–41
Molybdenum trioxide	MoO_3	66

Table 4.17 Commonly available sources of iron (Fe)

Source	Formula	% Fe
Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	19–21
Ferric sulfate	$Fe(SO_4)_3 \cdot 4H_2O$	23
Ferrous ammonium sulfate	$(NH_4)_2SO_4$ - $FeSO_4 \cdot 6H_2O$	14
Ferrous ammonium phosphate	$Fe(NH_4)PO_4 \cdot H_2O$	29
Iron chelates	NaFe EDTA	5–14
	NaFe HEDTA	5-9

Table 4.18 Equivalent measurements

	Length	
1 in.	= 2.54 cm	= 25.4 mm
1 ft	= 12 in.	= 30.48 cm
1 yd	= 3 ft.	= 0.914 m
1 m	= 39.37 in.	= 1000 mm
1 dm	= 10 cm	= 100 mm
	Area	
1 acre	= 43,560 ft^2	= 0.4047 ha
1 ha	= 2.471 acres	= 10,000 m^2
	Weight	
1 oz	= 28.35 g	
1 lb	= 16 oz	= 453.6 g
1 kg	= 2.205 lb	= 1000 g
1 ton	= 2000 lb	= 907 kg
1 metric ton	= 2205 lb	= 1000 kg
1 gal. of water	= 8.34 lb	= 3.78 kg
1 ft^3 of water	= 62.4 lb	= 28.3 kg
1 mg/liter	= 1mg/dm^3	= 1 ppm
	Volume	
1 cm^3	= 1 ml	
1 tbsp	= 3 tsp	= 14.8 ml
1 fl oz	= 2 tbsp	= 29.6 ml
1 cup	= 8 fl oz	= 236.6 ml
1 pt	= 16 fl oz	= 473.1 ml
1 qt	= 32 fl oz	= 946.2 ml
1 gal.	= 128 fl oz	= 3785 ml
1 gal.	= 3.785 liter	= 231 $in.^3$
1 liter	= 33.81 fl oz	= 1000 ml
1 liter	= 1.057 qt	= 0.2642 gal.
1 acre-inch	= 27,167 gal.	
1 yd^3	= 27 ft^3	= 22 bu
1 bu	= 1.25 ft^3	
1 dm^3	= 1000 cm^3	
	Yield or Rate	
1 ton/acre	= 45.9 lb/1000 ft^2	= 41.3 lb/100 yd^2
1 lb/1000 ft^2	= 0.9 lb/100 yd^2	= 0.02 ton/acre
1 lb/ft^3	= 9 lb/yd^3	
1 kg/ha	= 2 mg/dm^3	= 0.89 lb/acre

Table 4.19 Conversion factors for English and metric units

Multiply	To Obtain	Multiply	To Obtain
acre-inch by 102.8	m^3	ft^3 by 28.29	liters
acre by 0.004	km^2	ft^3 by 0.28	hectoliter
acre by 0.405	ha	ft^3 by 57.72	pint
bushel by 1.24	ft^3	ft^3 by 28.86	quart
bushel by 4	peck	ft^3 by 0.8	bushel
bushel by 0.046	yd^3	gallon by 3785	cm^3
bushel by 0.352	hectoliter	gallon by 0.1337	ft^3
bushel by 35.24	liters	gallon by 231	in.^{3}
centigram by 0.01	gram	gallon by 0.0038	m^3
centiliter by 0.01	liter	gallon by 0.005	yd^3
cm by 0.3937	in.	gallon by 3.79	liter
cm by 0.01	meter	gallon by 8	pint
cm by 10	mm	gallon by 4	quart
cm^3 by 0.000035	ft^3	gallon by 8.3453	lb of water
cm^3 by 0.06	in.^{3}	gram by 0.01	kg
cm^3 by 0.000001	m^3	gram by 1,000	mg
cm^3 by 0.000001	yd^3	gram by 0.035	oz
cm^3 by 0.00026	gal.	gram by 0.0022	lb
cm^3 by 0.001	liter	hectare by 2.471	acre
cm^3 by 0.002	pint	hectogram by 100	gram
cm^3 by 0.001	quart	hectoliter by 100	liter
decigram by 0.1	gram	hectoliter by 3.532	ft^3
deciliter by 0.1	liter	hectoliter by 2.838	bushel
decimeter by 0.1	meter	hectometer by 100	meter
°C + 17.78 by 1.8	°F	hundredweight by 0.454	quintal
°F – 32 by 5/9	°C	in. by 2.54	cm
dekagram by 10	gram	in. (thickness) by ft (length)	board ft
dekaliter by 10	liter	in.^{3} by 16.39	cm^3
dekameter by 10	meter	in.^{3} by 0.0006	ft^3
fathom by 6.0	ft	in.^{3} by 0.00002	m^3
ft by 30.48	cm	in.^{3} by 0.00002	yd^3
ft by 12	in.	in.^{3} by 0.0043	gallon
ft by 0.3048	meter	in.^{3} by 0.0164	liter
ft by 0.333	yd	in.^{3} by 0.0346	pint
ft^3 by 28,316.85	cm^3	in.^{3} by 0.0173	quart
ft^3 by 1,728	in.^{3}	in.^{3} by 16.39	cm^3
ft^3 by 0.028	m^3	kg by 2.205	lb
ft^3 by 0.037	yd^3	kg by 0.001	ton (short)
ft^3 by 7.48	gallon	kg by 1,000	gram

Table 4.19 (cont.) Conversion factors for English and metric units

Multiply	To Obtain	Multiply	To Obtain
kiloliter by 1000	liter	m^3 by 1056.8	quart
km by 100,000	cm	m^3 by 0.0097	acre-inch
km by 3281	ft	mile by 160,934	cm
km by 1000	meter	mile by 5280	ft
km by 0.62	mile	mile by 1.609	km
km by 1094	yd	mile by 1760	yd
km^2 by 247.1	acre	mph by 44.70	cm/sec
km^2 by 0.386	mi^2	mph by 88	ft/min
lb by 16	oz	mph by 1.467	ft/sec
lb by 0.0005	ton (short)	mph by 1.609	km/hr
lb by 453.59	gram	mph by 0.8696	knot
lb by 0.454	kg	mph by 26.82	meter/min
lb of water by 0.02	ft^3	mg by 0.001	gram
lb of water by 34.56	$in.^3$	ml by 0.001	liter
lb of water by 0.12	gal.	mm by 0.1	cm
liter by 1000	cm^3	mm by 0.04	in.
liter by 0.035	ft^3	oz by 0.06	lb
liter by 61.02	$in.^3$	oz by 28.35	gram
liter by 0.001	m^3	oz (fluid) by 2	tbsp
liter by 0.0013	yd^3	oz (fluid) by 6	tsp
liter by 0.26	gal.	oz (fluid) by 1.805	$in.^3$
liter by 2.12	pint	oz (fluid) by 0.03	liter
liter by 1.06	quart	ppm by 8.345	lb/million gallon
liter by 0.028	bushel	peck by 0.25	bushel
meter by 100	cm	quart by 47.75	$in.^3$
meter by 3.28	ft	quart by 0.95	liters
meter by 39.37	in.	quintal by 2.205	hundredweight
meter by 0.001	km	tbsp by 0.5	oz
meter by 1000	mm	tbsp by 3	tsp
meter by 1.094	yd	ton (long) by 1016	kg
m^3 by 35.32	ft^3	ton (long) by 2240	lb
m^3 by 61,030.4	$in.^3$	ton (long) by 1.12	ton (short)
m^3 by 1.35	yd^3	ton (metric) by 1.102	ton (short)
m^3 by 264.2	gallon	ton (metric) by 1000	kg
m^3 by 1000	liter	ton (metric) by 2205	lb
m^3 by 2113.6	pint	ton (short) by 2000	lb

Table 4.19 (cont.) Conversion factors for English and metric units

Multiply	To Obtain
ton (short) by 32,000	oz
ton (short) by 907.18	kg
ton (short) by 0.89	ton (long)
ton (short) by 0.91	ton (metric)
tsp by 0.167	oz
tsp by 0.33	tbsp
yd by 0.914	meter
yd^3 by 764,555	cm^3
yd^3 by 21.8	bushel
yd^3 by 27	ft^3
yd^3 by 46,656	$in.^3$
yd^3 by 0.76	m^3
yd^3 by 202	gallon
yd^3 by 764	liter
yd^3 by 1,616	pint
yd^3 by 808	quart
Fertilizer Conversion Factors	
phosphorus (P) by 2.29	phosphate (P_2O_5)
potassium (K) by 1.20	potash (K_2O)
Units-per-Area Conversion Factors	
bushel/acre by 0.87	hectoliter/ha
bushel (corn) /acre by 0.062 ton (metric)/ha	
bushel (soybeans) /acre by 0.067	ton (metric)/ha
bushel (wheat) /acre by 0.067	ton (metric)/ha
bushel (grain sorghum) /acre by 0.056	ton (metric)/ha
hectoliter/ha by 1.15	bushel/acre
hundredweight/acre by 1.12 quintal/ha	
kg/ha by 0.89	lb/acre
lb/acre by 1.12	kg/ha
mg/dm^3 by 2.0	kg/ha
quintal/ha by 0.892	cwt/acre
ton (metric)/ha by 0.446 ton (short)/acre	
ton (short)/acre by 2.24 ton (metric)/ha	